RMRS-99116-RJVA

Thesis/
Reports
Rack,
J.

Annualized Integrated Inventory and Monitoring Initiative

FINAL REPORT

Resource Assessment Unit, Division of Forestry
Minnesota Department of Natural Resources
413 SE 13th Street, Grand Rapids MN 55744

Jim Rack, Image Analyst
Ken Boss, Web Developer
Timothy Aunan, Research Analyst
Bill Befort, Remote Sensing Coordinator
David Heinzen, Supervisor

December 2002

ROCKY MOUNTAIN RESEARCH STATION LIBRARY
FORT COLLINS CENTER
240 W PROSPECT RD
FORT COLLINS, CO 80526-2098

Contents

Page

General Introduction 4

GIS Testbed Database 5

PlotView: Web Retrieval and Display of Plot-Level Imagery and GIS Data
- Introduction 7
- Map Interface 8
- Plot Data Access 10
- Supporting Software 10
- Further Information 11

FIA and NRI Change Mapping
- Introduction 12
- Procedures 12
- Kriging 12
- Change Areas 14
- Maps and Their Comparison 14
- Summary 14

Land Cover Classification and Change Detection in NRI/FIA Integration
- Introduction 15
- Classification Scheme 15
- Study Area 16
- Imagery 17
- Preprocessing 17
- Database Manipulations 17
- Image Processing and Classification 18
- Introduction of Homogeneity Measures 20
- Comparative Analyses 21
- Accuracy Assessment Matrices 22
- Land Cover/Use Change Analysis 22
- Results and Discussion 24
- Area Estimates from Inventories and Maps 27

Appendices
- Appendix A: Draft NRI/FIA Crosswalk 34
- Appendix B: Error Matrices from Satellite Image Classifications 38

Figures and Tables

Page

Figures:

1. GIS testbed database 5
2. PlotView map interface 7
3. Plot location overlaid on digital orthophoto quadrangle 8
4. Original scanned FIA fieldsheets in PlotView 9
5. A portion of the combined NRI/FIA point map 13
6. Study area covering Twin Cities metropolitan area of Minnesota 16
7. A portion of one 1996 classification of the metropolitan area 21
8. Accuracy of various training sets, August 1986 image 25
9. Accuracy of various training sets, July 1996 image 25
10. Estimated acreages from field inventories 29
11. FIA acres estimated and mapped – 1986 image 30
12. FIA acres estimated and mapped – 1996 image 31
13. NRI acres estimated and mapped – 1986 image 32
14. NRI acres estimated and mapped – 1996 image 33

Tables:

1. Change category point totals 23
2. Estimated acreages from field inventories 28

General Introduction

This report covers contracted activities of the Resource Assessment Unit, Forestry Division, Minnesota Department of Natural Resources, in exploring opportunities for integrating two similar but independent U. S. Department of Agriculture natural resource inventory systems.

Forest Inventory and Analysis (FIA) is conducted by the USDA Forest Service as its primary continuing source of national and state-level information about the condition of American forests of all ownerships (http://fia.fs.fed.us/). The National Resources Inventory (NRI) is conducted by the Natural Resources Conservation Service (NRCS) to track the condition of soil, water and related resources on all nonfederal lands (http://www.nrcs.usda.gov/technical/NRI/). Both inventory systems are based on aerial photo and field measurements of hundreds of thousands of permanently established plots.

The Resource Assessment Unit has been actively involved with FIA for decades, carrying out field operations in northern Minnesota in conjunction with the Forest Service's North Central Research Station. In the 1990s it began assisting NRCS in the aerial photo phase of NRI. In summer 1999 the Forest Service and NRCS concluded cooperative agreements with Resource Assessment to explore ways and means of integrating the two inventories. Activities were organized into four categories:

- Produce a statewide Minnesota "testbed" geographic information system (GIS) database incorporating FIA, NRI, and ancillary data.
- Develop a world-wide web intranet application for viewing plots over maps, photos and satellite imagery, and retrieving original plot data.
- Apply geostatistical tools to NRI and FIA plot data to map land cover/use, and changes in land cover/use over time.
- Using inventory plots as training data, perform satellite image-based land cover/use classification and change detection for a one-scene test area between two dates.

Accomplishments under these headings are described in the following pages.

GIS Testbed Database

A GIS testbed was assembled as an example of the possibilities for viewing, querying, and performing spatial analyses on spatial and tabular attribute data from the two inventories in combination with a variety of commonly used ancillary datasets.

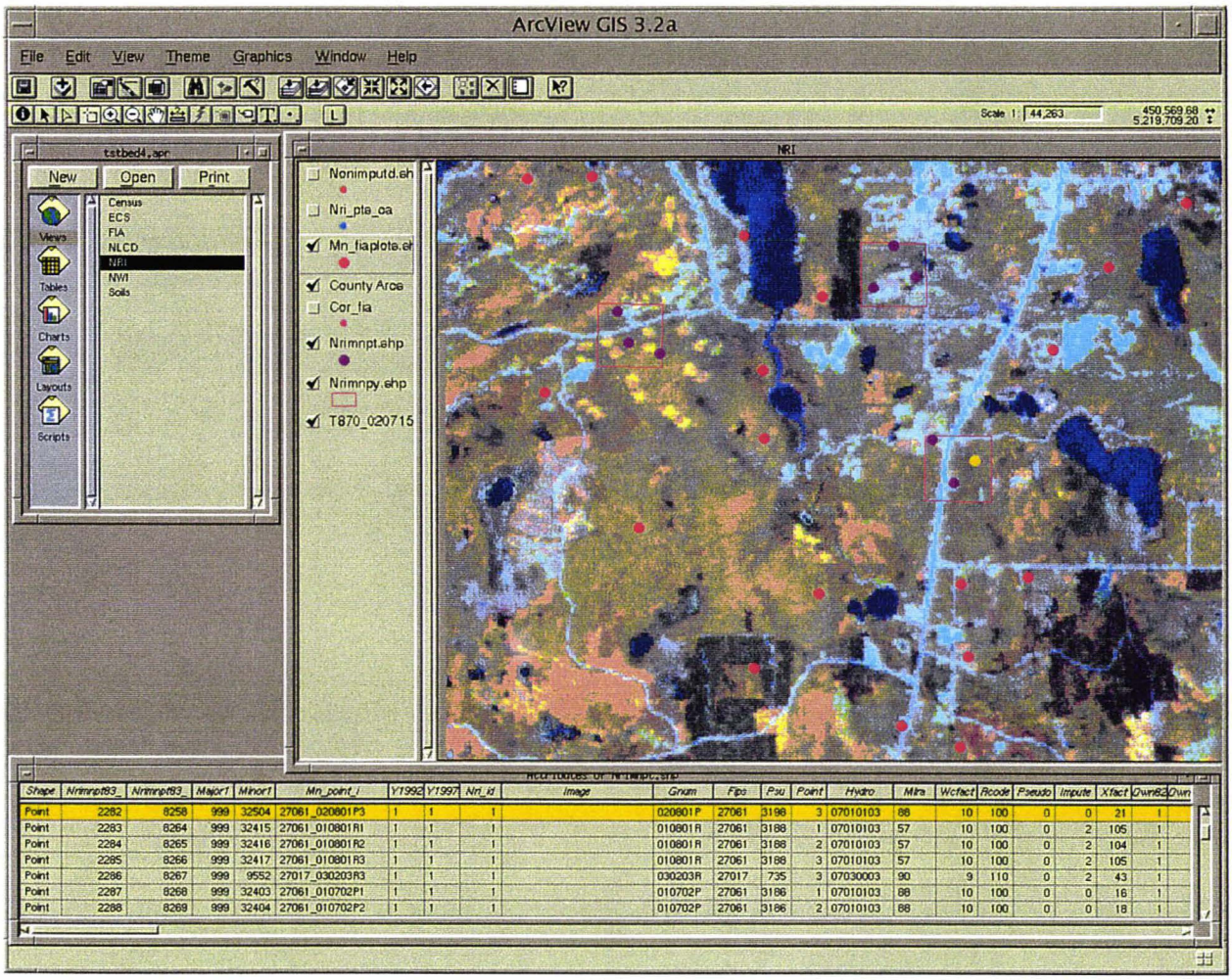


Figure 1: The GIS testbed database was created to run on ESRI ArcView software. This example shows FIA and NRI permanent plots displayed against a Landsat Thematic Mapper satellite image. NRI plot data are tabulated at bottom.

Datasets were converted into a common projection and coordinate system and loaded into ESRI ArcView 3.2, a commonly used GIS (http://www.esri.com/software/arcview/index.html), to allow accurate overlay and analysis of spatial data. The following datasets, all available nationwide, were included in the testbed:

- NRI – Point and polygon spatial data and associated tabular attributes.
- FIA – Point spatial data and associated tabular attributes.
- Forest Health Monitoring (FHM) of the USDA Forest Service – Point spatial data and associated tabular attributes.
- STATSGO Soils data of the USDA-NRCS – Polygon spatial data and associated tabular attributes.
- 1990 Census of the U.S. Census Bureau – Polygon spatial data and associated tabular attributes.
- National Land Cover Data (NLCD) of the U.S. Environmental Protection Agency (EPA) Multi-Resolution Land Characterization Consortium (MRLC) – Raster spatial data and associated tabular attributes.
- Digital Elevation Model (DEM) of the United States Geological Survey (USGS) – Raster spatial data with elevation attribute.
- National Wetlands Inventory (NWI) of the U.S. Fish and Wildlife Service (USFWS) – Polygon spatial data and associated tabular attributes.
- Digital Raster Graphics (DRG) – Scanned GeoTIFF format images of USGS 7.5 minute quadrangle maps.
- Digital Orthophoto Quarter Quads (DOQQ) – GeoJPEG images of orthorectified National Aerial Photography Program 1:40,000 scale aerial photography.

Additional data layers available only for Minnesota were also included to illustrate potential applications. These included Ecological Classification System polygons, Gap Analysis Program (GAP) land cover raster data, GAP land stewardship polygons, Landsat Thematic Mapper imagery, Minnesota DNR Cooperative Stand Assessment forest stand polygons, Public Land Survey township and section polygons, and supplemental digital aerial photography.

This testbed of data layers successfully demonstrated the capabilities of ArcView 3.x to manage, display, query, link, join, and "hot link" (i.e., bring forward ancillary imagery or data by selecting a spatial feature) a variety of spatial and tabular information. Having this wide array of spatial data in a GIS environment together with inventory plots allows for the complex analyses and modeling required in modern natural resource planning efforts.

--Jim Rack

PlotView: Web Retrieval and Display of Plot-Level Imagery and GIS Data

Introduction

Thanks to a NASA-funded research partnership with the University of Minnesota, the Resource Assessment Unit acquired early experience delivering map and image data online in GIS-type formats on its ForNet website (http://www.ra.dnr.state.mn.us). On the basis of this experience, Resource Assessment was asked to create a web application providing interactive, map-based access to FIA and NRI plot data in a password-protected environment. This took shape as PlotView (http://www.ra.dnr.state.mn.us/plotview), designed to access centrally maintained stores of plot data from anywhere an internet connection is available. Its design obviates any need for duplication of large image datasets, while providing instantaneous access to inventory data from any location, avoiding the lengthy delays typical in the past.

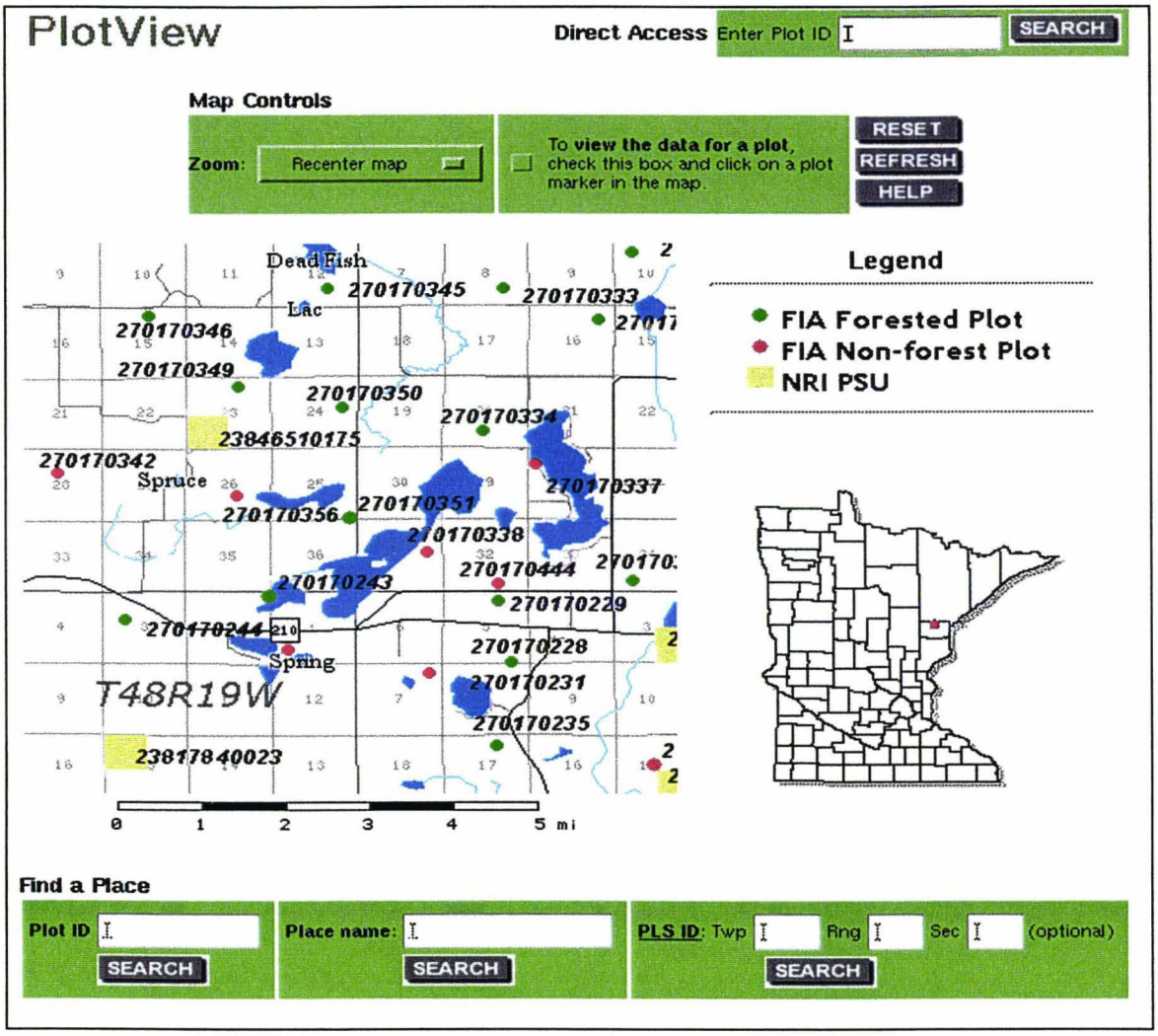


Figure 2: PlotView's versatile map interface lets users navigate to NRI/FIA plot data using plot numbers, place names, legal descriptions, map data or satellite images. (Actual plot locations altered.)

Map Interface

A major strength of the PlotView application is that it enables users to view plot locations in a landscape context via online maps. The user may navigate by whatever means are handiest, whether by place name searches, Public Land Survey descriptions, map coordinate input, or point-and-click pan/zooming on the map itself. The map view may be toggled to give a satellite image view, allowing visual identification of cultural and natural features in proximity to plots.

Figure 3: Plot location overlaid on digital orthophoto quadrangle in PlotView.

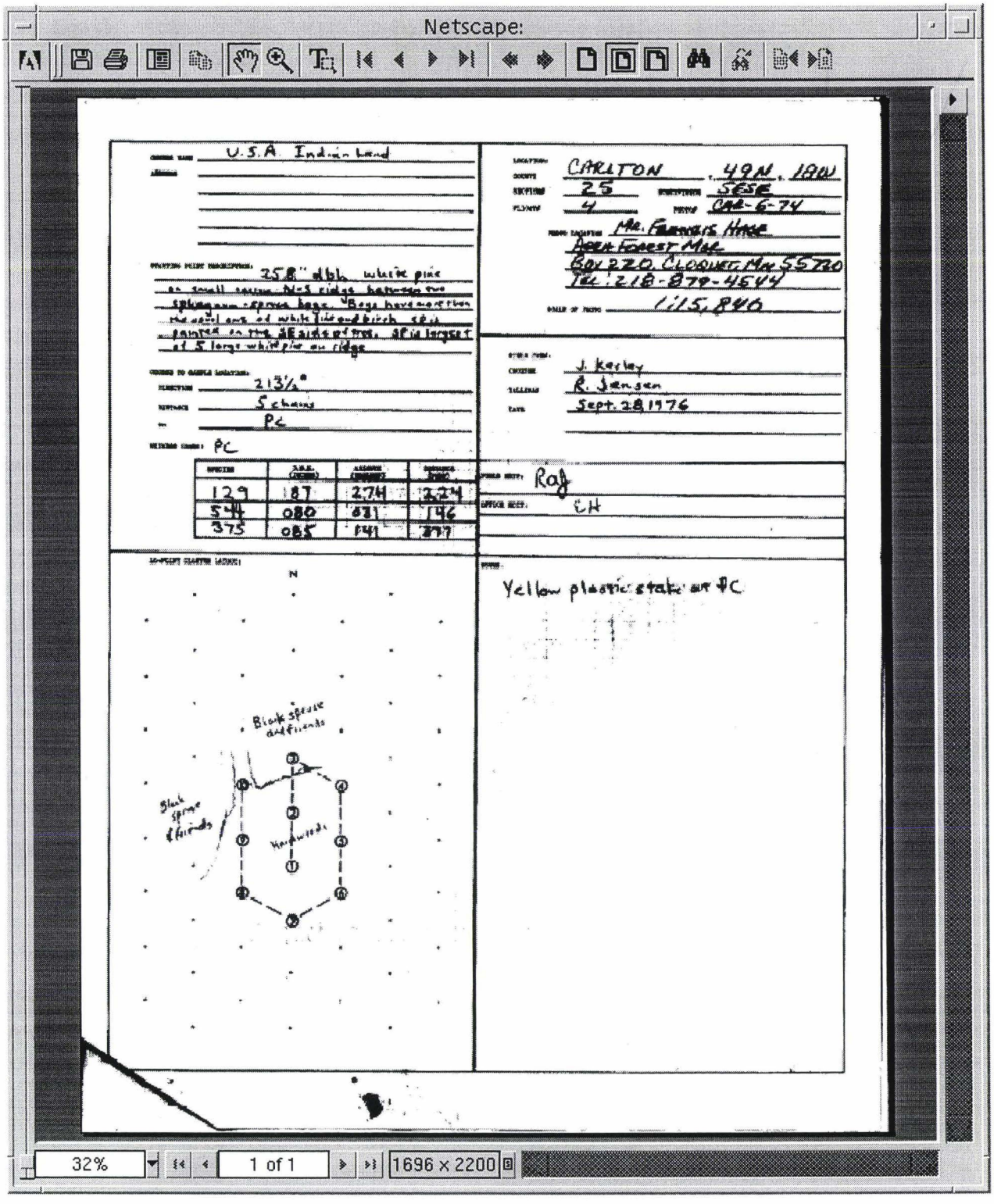


Figure 4: Original scanned FIA fieldsheets are among the plot data elements instantly retrievable with PlotView.

Plot Data Access
Data pertaining to a given plot can be accessed either by entering the plot ID into a text box in the interface, or by clicking the plot centroid symbol on the map. Data returned for a given plot may include any or all of the following:

- Scanned aerial photographs: Any quantity of inventory-specific photos taken over the plot through the years, and other generic photo resources such as NHAP, NAPP or state and local photographic holdings, whether rectified or not.

- Scanned fieldsheets: These FIA documents contain individual-tree and subplot data, and hand-drawn maps showing plot access routes (Figure 4).

- Plot-specific database contents: Database outputs specific to a given NRI plot are available through the Dataview web application at Iowa State University. Integration with similar FIA plot databases is also possible.

- DRGs (digital raster graphics, scanned USGS quad maps): These are presented in seamless fashion, so that users can view any area without regard to the boundaries of the original paper maps, overlaid with other data, including plot centroids and labels.

- DOQQs (quad-based orthorectified photography from USGS): As with DRGs, DOQQs are presented in a "seamless" mode, so that any area of interest may be viewed without regard to original photo boundaries, overlaid with user-selected GIS data, including plot centroid and label (Figure 3).

Supporting Software
All software driving PlotView is freely distributable under open-source licenses:

- MapServer (http://mapserver.gis.umn.edu) provides the interactive web-mapping capabilities.

- Perl (http://www.perl.com) is the scripting "glue" that holds the various pieces together.

- MySQL (http://www.mysql.com) is the database system containing the metadata for the variety of data elements associated with the plots. PlotView does not require MySQL in particular; nearly any web-accessible database system (e.g. Oracle, Sybase, Informix) may be substituted.

- Apache Web Server (http://www.apache.org) is Web-serving software. As with the database software, a variety of other web-serving packages may be substituted.

- PDFlib (http://www.pdflib.com) is a PDF file format generator, enabling PDF encapsulation of images and maps for printing.

Two proprietary software products, while not required to run PlotView, are extremely useful in preparing GIS and image data for web distribution:

- ArcView or Arc/Info (http://www.esri.com) is the ESRI GIS software used to prepare the map datasets served with MapServer. MapServer is now at the point of incorporating the OGR and GDAL open source software libraries; this will greatly expand the sources of both vector and raster GIS data PlotView can work with.

- MrSID Encoder (http://www.lizardtech.com) wavelet compression software enables speedy delivery of large image datasets over the internet.

Further Information

PlotView is best understood by visiting the web site itself, at the URL listed in the introductory section. A user-ID and password are necessary to access the site. For obvious reasons these cannot be given here; contact your FIA program manager or NRI ICCS leader for this information. Any technical or administrative questions may be directed to the author.

--Ken Boss

Change Mapping With FIA and NRI Plot Data

Introduction

There are more than 36,000 FIA plots in Minnesota, and nearly 23,000 NRI sample points. The total comes to nearly one point for every 1.5 square miles in the state, although the actual distribution is less regular than this suggests. The high density of data points seemed to indicate that a geostatistical approach using combined FIA/NRI plot data across a span of years might yield useful state-scale maps of land cover status and trends. The following sections describe how the two plot arrays were combined, and the products that resulted.

Procedures

The mapping goal was to display all NRI/FIA plots in Minnesota, highlighting those that showed land use change across the time interval studied. FIA land use data were available for 1977 and 1990, and NRI data for 1982 and 1992. As the two inventories employ different typologies, a crosswalk was created to reclassify specific land use codes from each dataset into the five common categories of Crop, Forest, Herbaceous, Urban and Other. These crosswalks are tabulated in Appendix A.

GIS point databases in ESRI Arc/Info coverage format were used to create the maps. Not all points contained valid land use codes for the associated years; those without them were eliminated. As NRI point samples are grouped within (approximately) 160-acre primary sampling units (PSUs), for display purposes it was necessary to ungroup them by doubling their distance from the PSU centroid.; this at once eliminated overlapping map symbols and added security to the actual plot locations. FIA plot locations were similarly protected by randomizing their coordinates within 1 kilometer of their actual positions.

With the crosswalk and the map point selection attributes in place, the points were then placed in ESRI ArcMAP 8.1 map documents. By combining one symbol shape for each of the five Time 1 categories and one color for each of the five Time 2 categories, each point on the map could show the land use crosswalk code for both years, as illustrated in Figure 5. A second set of maps displayed only those points that had changed from one crosswalk category to another. These used the same symbology and parameters as the first set of maps, except that points with no change were left out.

Kriging

An attempt was made to interpolate land use surfaces by kriging analysis in a limited area of the map, but visual examination of the results showed no discernible relationship to the values in the point datasets.

This type of analysis, however, might prove fruitful in the future, potentially providing polygonal and/or continuous surface estimates to compare between inventory types or over time. This would require detailed understanding of both the interpolation technique and the NRI and FIA point datasets.

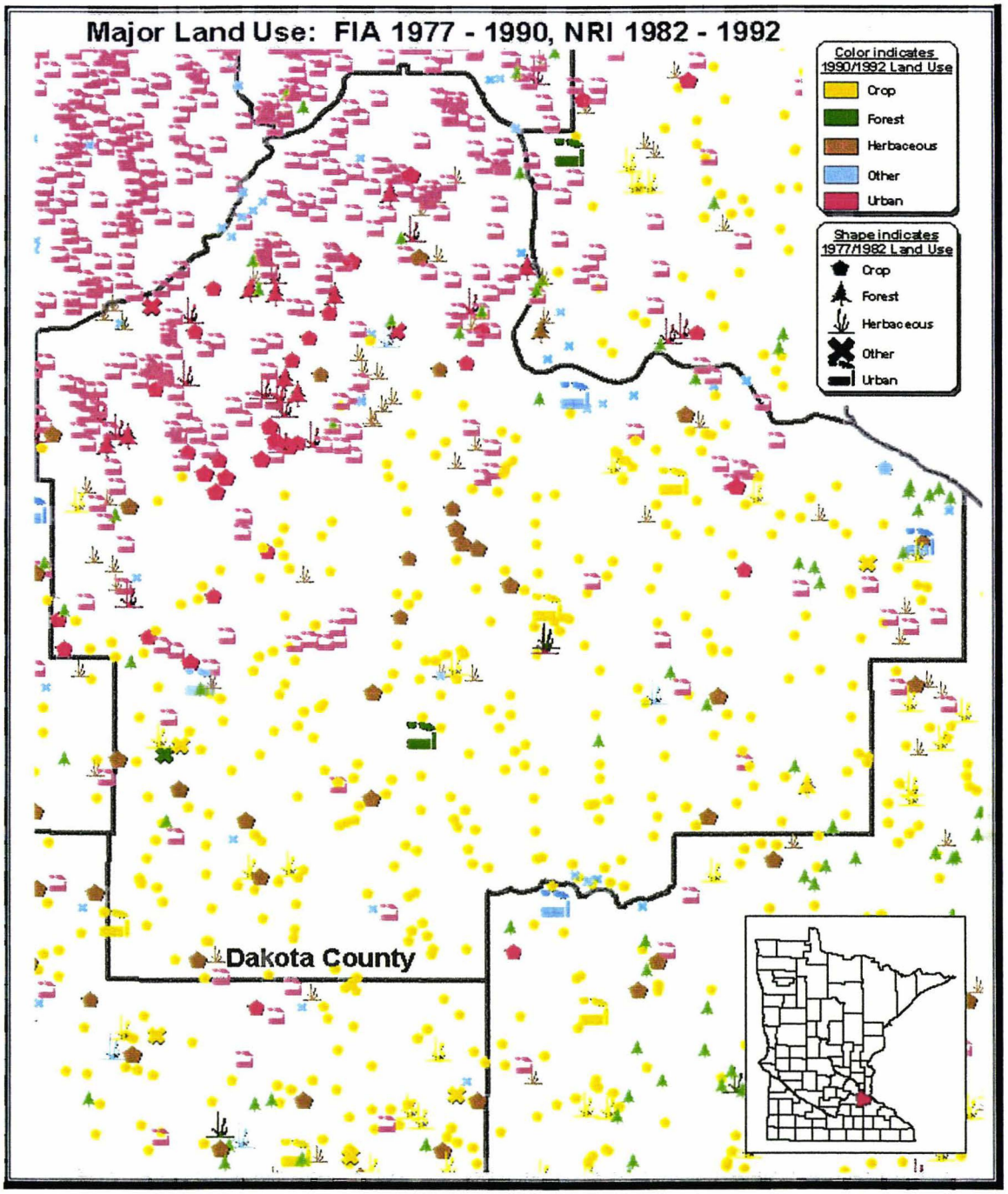


Figure 5: A portion of the combined NRI/FIA point map, centered southeast of the Minneapolis/St. Paul metropolitan area. Symbol shapes indicate land use category of each plot at Time 1; colors indicate plot land use category at Time 2. Bolder, darker symbols indicate points at which land use changed between the earlier and later survey dates.

Change Areas
After the first sets of maps were printed, inspection revealed patterns of change in the state. As could be expected, many plots on the edge of the Minneapolis / St. Paul area and along the St. Cloud corridor showed change to Urban from the other four categories, especially from Crop and Forest. Along the Mesabi iron range many Urban plots changed to Forest as pits and overburden piles revegetated; southwest of Leech Lake near Park Rapids, Forest plots changed to Crop as jack pine timberland was converted to potato fields serving a major processing plant built in the 1980s.

Such changes are relatively easy to document, and reflect well-known developments. North of Red Lake, however, where numerous FIA Forest plots changed to the Other category, more care was required in interpretation. Most of the changed FIA codes there went from 40 (unproductive forest land) to 65 (marsh). Field personnel familiar with the area, including some who had been involved in both FIA iterations, suggested that the changes were more apparent than real, having to do with shifts in photointerpreters' perceptions, FIA procedures, and plot centroid locations. Plots photointerpreted as unproductive forest were not field-visited in the 1977 inventory, but were field-visited in the 1990 inventory; this could easily have led to the reclassification of many as non-forest, especially if the plot centroid shifted slightly from one inventory to the next – as was very likely to happen in a region of few landmarks, in the years before Global Positioning Systems (GPS) and precisely rectified aerial photographs.

Maps and Their Comparison
The combined FIA/NRI plots constitute an easily used geographic pointer dataset, whose patterns indicate significant areas and types of land use change across the state. Interpreting the change maps, however, requires ancillary data. Both inventories' land use categories must be generalized to a great extent to merge them, and the difference in their time-spans adds a level of complexity. Further, NRI and FIA use different spatial sampling methods, which become evident when the plots are mapped and compared. Because NRI points are grouped in PSUs, the 22,724 samples in that inventory generally occur in tight clusters of three, which reduces their apparent spatial resolution to about ¼ that of the 36,285 FIA plots. The unclustered FIA plots tend to reveal to the eye patterns less readily apparent from the NRI plots viewed alone.

Summary
Combining two such complementary datasets is an obvious way of detecting and displaying broad land use change patterns at a statewide scale. Not surprisingly, NRI shows more agricultural attribute detail than FIA, and FIA points reveal more forest differences than NRI. The two inventories are natural partners; with more attention to compatibility of land use definitions and field methods, the value of the combination could be substantially increased. For GIS applications, the importance of accurate plot location data cannot be overemphasized.

--Tim Aunan

NRI/FIA Integration in Land Cover Classification and Change Detection

Introduction

This exercise began as an attempt to shed light on the ability of an integrated set of FIA and NRI points to produce improved satellite maps of land cover and change across on a landscape. The procedures outlined here describe how point data from the inventories can be used to create training data that allow classification of medium-scale satellite imagery.

Classification Scheme

Each inventory has its own focus, and their definitions of land cover/use are somewhat disparate. NRI is focused on agricultural uses and cover on non-federal lands, and pays less attention to other lands and uses. This specialized focus can be readily seen in the difference in detail measured for agricultural lands, as opposed to forested or wetland cover types. An almost opposite pattern is present in FIA data, in which forestlands are measured in great detail, while other uses get only coarse labels and no measurements are taken.

The first step was to define a classification scheme and develop a crosswalk between each of the inventories and that scheme. The initial classification scheme is composed of five classes:

Forest
Cultivated Crop (or Row Crop)
Herbaceous Crop (Hay and Pasture)
Urban (Industrial, Commercial, and Residential)
Other (Miscellaneous covers including water)

Local experts developed a crosswalk between each of the inventories and these five output classes. The crosswalks are tabulated in Appendix A.

Many of the points remain confused due to limited discriminatory data collected at some locations, or complications of lumping as discussed in Appendix A. One of the major complications is that many of the inventory categories are focused on a subjective "use" that is readily recognizable by observers on the ground or from aerial photography, whereas multispectral analysis of satellite imagery with 30-meter picture elements (pixels) is more adept at identifying "cover" and has difficulty discriminating "use." An example is the FIA label of "right of way" for roads, pipelines, power lines, and railroads. The crosswalk labels these plots Urban. While multispectral pixel data may accurately label a non-vegetated roadway as Urban, problems will arise with pipeline and power line rights of way, which may contain vegetation that is spectrally confused with Herbaceous, Crop, or marshland areas.

The Urban class as a whole is a key example of this problem, as well as a class of great interest when discussing landscape change. Trees, grass, and shrub cover can all fall into the Urban

"use" class in either of the inventories, as in a wooded suburb where the cover is trees, but the use is residential (Urban). A photo interpreter observes the trees, and deduces the "use" from context, neighboring covers, extent, etc.; this subjectivity makes the label less repeatable when the site interpreted again at some later time by a different interpreter.

The use-versus-cover question complicates the labeling of changes. A field point may correctly show a change from Forest to Urban land use class, while multispectral information over the time span continues to reflect tree cover – the use of the land has shifted, but from the spectral standpoint little has changed. That is, spectral data measured by a satellite for the immediate environs of a plot are more repeatable over time, but more limited than the discriminatory talents of a human analyst when it comes to distinguishing land "use." Extensive modeling work can help arrive at a proper "use" label, but is time- consuming and costly.

Any attempt to meld two inventories with very different emphases into a single classification scheme poses difficulties. The power of combining the inventories to obtain reduced standard errors of estimate and more samples for training of classifiers is countered by the problems of accurately cross-walking non-forest classes in FIA and forest classes in NRI into appropriate output class, mainly on account of the reduced measurement quantity and quality applied to the "not-of-interest" classes. It would be beneficial in the long run for both inventories to agree on definitions for land cover/use classes, and to add attributes and minimum standards for field/photo interpretation techniques, so as to label points more consistently.

Study Area

A 10-county area around the Twin Cities Metro region, contained within a single Landsat scene, was selected for analysis (Figure 6). This area includes a diverse combination of land use classes, and contains a relatively high proportion of land use change due to progressive urbanization.

Figure 6: Study area covering Twin Cities metropolitan area of Minnesota

Imagery
Landsat 5 Thematic Mapper images used were from the northern portion of Path 27, Row 29, dated August 21, 1986 and July 15, 1996. Midsummer imagery is best for change detection due to stable vegetation phenology, though less than ideal for classification. Addition of spring or fall imagery would improve classification accuracy, but was precluded for budgetary reasons.

Preprocessing
Each image was rectified and georeferenced to the Minnesota DNR standard: Universal Transverse Mercator extended Zone 15 projection, North American Datum of 1983, GRS 1980 Spheroid. A road coverage from the Minnesota Department of Transportation (MnDOT) was used as as a standard of known accuracy in rectification. The 1986 image was additionally registered to the 1996 image in order to ensure that pixels overlaid the same area on the ground in both images; this step is critical in the change detection phase of the analysis. The overlap area of the two scenes within Minnesota was clipped out as an Area of Interest (AOI).

Image values were converted to reflectance – a standard ratio of reflected radiation that adjusts for differences in solar elevation, distance, and sensor differences over time between the two images. Eighteen "invariant" objects were selected in the AOI, representing the range from dark to bright reflectance, and regression analysis of values for both dates of these objects was used to to correct for differences in atmospheric conditions between dates. In this case the 1986 image was adjusted to match the 1996 image.

Clouds and cloud shadows were present in each image to a limited extent, and were manually digitized and removed from further analysis. They show up as Class 6, Cloud in the output.

Database Manipulations
Once the crosswalk between individual inventory information and the desired 5-class scheme was finished, each point sample from the two federal inventories was recoded to a new value. This was accomplished for the 1982, 1987, 1992, and 1997 NRI data as well as the 1990 FIA data and what I will call the 1996 FIA, which is a combination of 1990 FIA data updated with Annual Forest Inventory System (AFIS) information for 1993-1996. This yielded six different point coverages of the five classes as input data for further analyses.

Some of the NRI points are real points field-measured at a given location. Others are imputed (pseudo) points that provide generalized and supplementary information about the Primary Sampling Unit (PSU). Only the real points can be used for mapping spatial information. The real points were separated from the total and saved to train the classifier; the larger set was to be used only for area estimation.

The point coverages were converted to raster data at 30-meter resolution in order to make it compatible with image data. A 3x3 maximum-value filter was run over each raster image of point data in order to expand the area of the point to more closely represent the area of an FIA plot or an NRI point. Each point was now represented by 9 pixels, or about 2 acres.

Image Processing and Classification

There are many techniques for performing image classification. Results will vary considerably based on a number of factors such as the number and suitability of images, the quality of training data and ancillary information, and time spent in refining the classification process. The intention here was to compare a variety of different classification options.

The first classification attempt was on the July 15, 1996 image converted to reflectance. The 9-pixel "point" data from the 1997 NRI and the 1996 FIA were combined and broken down into AOIs for each of the five classes: Crop, Forest, Herbaceous, Other, and Urban. These pixels as a group then constituted the training data for that class.

If we accepted the point data expanded to 9 pixels as perfectly representing the labeled class at each point, we would build spectral "signatures" of each class from the spectral values at these points and run a "supervised" classification. This technique relies on using pixels of known information class to label unknown image pixels based on spectral similarity. However, the FIA/NRI plot data are far from perfect for this purpose. Sample points do not always fall in homogeneous areas in which all 9 pixels actually represent the same information class. Points frequently fall on boundaries between two classes or more. The recorded point location may be inaccurate. Field data may not have been collected in the same year as the imagery. In the presence of this kind of "noise" in the training set, a different, "unsupervised" approach is often used. This method statistically groups pixels based on their spectral similarity, and then relies on the analyst to label these clusters from the best information available.

Each class of training pixels was broken down using unsupervised (Isodata) techniques, in the ERDAS Imagine image analysis software system, into 20 crop, 15 forest, 15 herbaceous, 15 other, and 20 urban subclasses respectively, and the spectral signatures of these 85 classes were saved. Each set of subclasses represented the range of spectral variation within a particular class of training pixels; some of their signatures fell neatly into the parent category, while others represented confusion between two or more of the five desired output classes. These confused signatures can be broken down further with the same Isodata techniques and labeled iteratively until confusion is eliminated, and anomalous signatures are deleted or accepted as such.

The first step in subclass labeling was to use the 85 unsupervised signatures to classify the image, employing the standard maximum-likelihood decision rule, producing an output image in which each pixel in the image was assigned to the most likely (i.e. spectrally most similar) signature of the 85. This classified image, recoded to the original 5-class scheme, was given the label "i96_isofirst." It represents the quickest and simplest output from the training data. While it incorporates many flaws, it serves as a basis against which to compare refinements.

Each subclass may then be viewed separately and given a more appropriate label. Individual subclasses can be highlighted as an overlay of the original image, toggled on and off, and labeled by interpreting the image or ancillary data at the same location. An additional aid in signature evaluation is the "separability" feature of the Imagine signature editor, which displays the

statistical relationships of spectral signatures to one another, highlighting sources of confusion and helping decide whether to create a new label or to delete a particular signature. When necessary, a new signature may be added from a manually selected portion of the image to account for some small spectral class that may have been lost as a result of not specifying enough Isodata subclasses; this adds a supervised touch to an otherwise unsupervised classification.

An attempt was made to track the success of modifications and iterative improvements in classification by comparing relative percentages of the output classes against the relative percentages of the pixels used in training. Weighted estimates from the inventories could not be used at this time, as this was a combined FIA/NRI training set and only "real" NRI points were included. Although not a perfect comparison, it seemed to point in the right direction as new heuristic attempts were made to solve apparent problems.

The first apparent problem was confusion between deciduous forest and crop areas. Midsummer images of crops such as corn can be spectrally very similar to deciduous forest. Incorporating another image from the spring season when row crops are being planted on bare soil would go a long way towards solving this confusion in areas with substantial crop acreage. For this exercise, I assembled all the pixels containing this confusion and created an AOI that was used to break down these pixels into more unsupervised classes than originally specified. These subclasses were then labeled as before in hopes of identifying improved signatures.

Ancillary data also offer solutions to confusion, e.g. the National Wetlands Inventory (NWI) dataset may be used to separate wetland grass areas from crop and other herbaceous cover. The NWI is used to segment the scene into uplands and lowlands; confused classes can be recoded to Other if the NWI indicates lowland at that location, or left as Crop or Herbaceous if upland.

A road coverage also offers solutions for problems involving the Urban class. "Urban" as defined by the inventories is usually more a matter of land use than cover; satellite imagery has difficulty interpreting land use, and modeled solutions are essential. A current roads layer of known accuracy from MnDOT was used in the present case; TIGER line files from the U.S. Census would be a substitute if national coverage were required. Two modeling approaches were used: proximity and density functions. Proximity simply uses a specified distance from a road in a modeling statement. Density is more complicated, and requires running a spatial filter of suitable dimensions over the image and summing the road pixels in the window. I used a 7x7- pixel window that generated values from 0 to 39. These functions were used to change Urban pixels in obviously agricultural areas to Crop if they were not near or in an area of some density of roads. Such an approach also allows small areas of natural cover in proximity to urban areas to be classified as Urban. Census data could also be used to accomplish the same objectives.

Some final filtering was done to clean up "salt and pepper" pixels and to adjust the proportions of classes to more closely resemble the aforementioned training data. The output layer from these procedures is referred to as "i96_iatrix" in accuracy assessment matrices.

Introduction of Homogeneity Measures

Discussions with and documentation from Glenn Lawson of NRI offered options for training set development. Concepts of homogeneity and class inclusion of signatures were incorporated into further classifications, based on work previously done by Glenn on Iowa imagery. Procedures were functionally similar, but not identical since they had to be applied to FIA data as well.

Homogeneity was added to classification of the August 21,1986 image in an effort to improve the quality of the training data. The image data, rather than inventory data, was used to quantify homogeneity in order to eliminate temporal differences. This process began with calculating the first principal component from the six visible, near- and mid-infrared bands of imagery, concentrating the greatest part of the variability in the data into a single band. We fed this to a locally developed model in ERDAS Imagine and ran a 7x7-pixel standard deviation filter over the data, to calculate a standard deviation for the pixels in the filter window and apply that value at the center pixel. These new image composed of these values is a homogeneity image; the value at each plot location was added to the point databases as a new attribute.

The second phase involved setting a threshold of this homogeneity measure for each of the five classes of training points that would divide the point data in half. The more homogeneous half was again expanded to 9 pixels amd used to create AOIs of the combined FIA and NRI training sets as in the previous discussion. Training pixels that fell in clouded areas were eliminated from further analyses.

An unsupervised classification was run using 20, 10, 10, 10, and 20 classes using the Crop, Forest, Herbaceous, Other, and Urban AOIs respectively. The smaller number of unsupervised classes was necessitated by the smaller set of available training pixels.

The next improvement was to test each signature to see if it was classifying within training class when applied to the image, by assembling all signatures into one set of 70, running a supervised classification of the entire image using the maximum-likelihood classifier, and then cross-tabulating the pixels classified by each signature against the set of training pixels. A good signature should show a high percentage of pixels assigned to that subclass falling within the same class in the training data. An agreement of at least 75% was required for a signature to be retained, except in situations where this would eliminate most of the signatures for often-confused classes such as Crop/Herbaceous; in such cases, analyst discretion would dictate the threshold. The 44 retained signatures were used to classify the image; the resulting classification was recoded to the 5 output classes and is referred to as "i86_isofirst" in accuracy analysis.

From this point on, the full suite of image analysis procedures including visual inspection, "cluster busting," filtering, modeling, etc. were employed on the 1986 image as earlier with the 1996 image. The resulting image is referred to as "i86_iatrix" in accuracy assessment matrices.

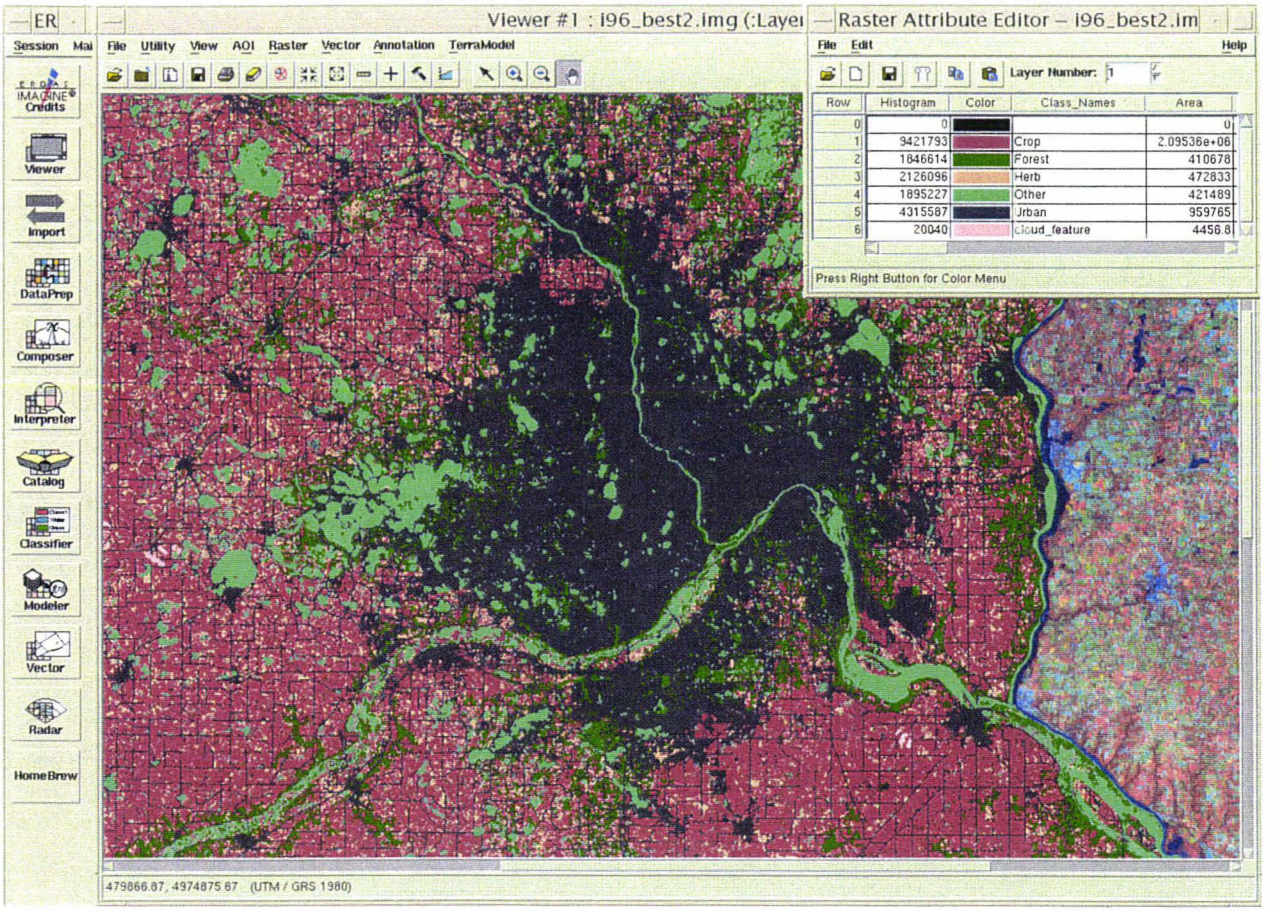

Viewer #1 : i96_best2.img (:Layer
Raster Attribute Editor – i96_best2.im
File Edit Help
Layer Number: 1
Row Histogram Color Class_Names Area
0 0 0
1 9421793 Crop 2.09536e+06
2 1846614 Forest 410678
3 2126096 Herb 472833
4 1895227 Other 421489
5 4315587 Urban 959765
6 20040 cloud_feature 4456.8
Press Right Button for Color Menu
479866.87, 4974875.87 (UTM / GRS 1980)

Figure 7: A portion of one 1996 classification of the metropolitan area

Comparative Analyses

Efforts up to this point were based on using the combined FIA and NRI inventory points as training to develop the best possible maps of land cover of the test area. The analyses take a turn at this point in an attempt to compare the effectiveness of these inventories, individually and in combination, as training data for mapping. The results indicate some of the strengths and weaknesses of individual inventories for these types of efforts; these observations may suggest possible changes in each of the inventories to make them more compatible and effective, as well as better training tools in multispectral land cover classification.

Ongoing review and discussions called for some changes to the common typology. Where NRI land cover/use codes were 613 (strip mines, quarries, gravel pits, borrow pits) or 619 (oil wasteland), they were recoded to Urban instead of Other. Where the land cover/use code was Forest but the NWI Cowardin code was 52 (palustrine-scrub-shrub), they were recoded to Other as well. A problem observed in the Other category from the early classification attempts was the wide spectral separation of water and vegetated subclasses. This led to a decision to create a separate Water training class for the 1987 NRI and 1990 FIA datasets.

A model was written to incorporate a generated random layer and thresholds of homogeneity. Half the FIA and NRI points were randomly set aside for accuracy assessment. The more homogeneous half of the remainder served as training points for classification. The training data were then tested at successive levels of refinement:

First, the training data were again classified with unsupervised techniques, and the signatures combined into one file of approximately 250 signatures. Those with too few pixels to allow the covariance matrix to be inverted (a requisite of maximum likelihood classification) were deleted. Signatures with fewer than about 7 pixels were not suitable. Classifications labeled "7up" (7 pixels and up) refer to this stage of analysis.

In the second stage, after the saved signatures were used to classify the entire image with the maximum likelihood classifier, the resulting image was cross-tabulated with the training pixels, and any signature producing 75 percent or less agreement with the same output class of the training data was also deleted. File names with "gt75" (greater than 75%) in them refer to this.

A third, separate "fuzzy" classification was performed, using the signatures with greater than 75% agreement for the 1990 FIA and 1997 NRI data. The output is a two-layer image file, the first layer containing the best single label, and the second layer containing the second-best label. More than two layers may be specified, and a distance file is created at the same time containing the Euclidean distance (in 6-dimensional image space) of pixel values from signature values. The two-layer fuzzy classification was run through a fuzzy convolution filter, which calculates a total weighted inverse distance of all the classes in a 3x3 window and assigns the class with the largest inverse distance to the center pixel. Results of this process are indicated by "fz2c" (fuzzy, 2 layers, convolution) in accuracy assessment tables.

Accuracy Assessment Matrices

At this point, accuracy assessment was performed on all classifications, to identify trends and draw preliminary conclusions about the comparative quality of training data and the classification scheme. Reference data for each of the two image dates included a randomly selected half of the real points from FIA, a similarly selected half of the NRI points, and a Combined FIA/NRI (CFN) set. Classification products from the 1986 image were compared to 1987 NRI and 1990 FIA data, and products from the 1996 image were compared to the 1996 FIA and 1997 NRI data. A complete set of error matrices is provided in Appendix B.

Land Cover/Use Change Analyses

The individual resource inventories can produce estimates of the magnitude of change among land cover/use classes for a landscape; image analysis offers the possibility of mapping change locations. A number of change-mapping techniques were attempted, with varying results.

Once classification of each date of imagery is completed, it is relatively simple to compare the two classifications and quantify the changes from any class to any other. The inherent problem with this technique is that classification errors are confounded with actual changes, and the expected accuracy of the result is no higher than the product of the accuracies of the input maps.

One alternative is to use plots known to have changed during the interval between images as training locations for classification of change. A 9-pixel area around these changed plots is selected and grouped, as in the previously described single-date classification efforts, according to the category of change, e.g. Crop to Urban. The images are combined to create a 12-band composite image. Signatures are built for each change category, refined visually and used to classify the composite image. This technique offers more flexibility in adjusting the areas of change categories to match the estimates of the individual or combined inventories. The difficulty is that some change-class estimates may be based on too few plots to have acceptable standard errors associated with them, or represent the range of spectral variation within the class.

The following table shows how many points were found for each change category between the 1987 and 1997 NRI and the 1990 and 1996 FIA.

Table 1. Change category point totals

Change	NRI	FIA
Crop to Urban	34	0
Forest to Urban	41	1
Herbaceous to Forest	12	0
Herbaceous to Other	9	0
Herbaceous to Urban	73	0
Other to Urban	11	0

Using inventory points as training data for developing signatures for change categories was unsatisfactory in the test area for the time span 1986 - 1996. Signature refinement techniques for Crop to Urban, Forest to Urban and Herbaceous to Urban were problematic, and the classes exhibited confusion with areas that had not changed. Even in the fast-changing Twin Cities metropolitan area, there were too few change plots to provide good signatures across the range of spectral variability. Rare change classes, or change classification in areas with little urban development, would be even more problematic. Only intensifying the sample or expanding the time span would be likely to yield enough change data for this approach.

Tim Aunan's work with point data from both inventories exposed an additional problem when looking at change over time: inaccurate plot coordinates. Maps developed for the field tour segment of the August 2002 project meeting revealed that photo plots interpreted for the 1977 FIA inventory were not consistently located with respect to 1990 sites, giving rise to spurious changes such as "urban to forest." Accurate plot location over time is an obvious prerequisite if plot data are to be used in any form of change mapping. The general adoption of GPS equipment and the increasing demand for precise co-registration of spatial datasets will probably enable better work to be done in change classification in the future.

A third change-mapping approach used image differencing to map change, with the inventory points serving as ancillary data for corroboration of appropriate labels and as *a priori* estimates of the quantity of each change category within the study area. This approach combined the change detection capabilities of multispectral remote sensing and the wealth of information contained within the individual inventories. The multispectral data are transformed to Kauth-Thomas brightness, greenness and wetness values, and between-date differences are saved as a 3-band image, "delta BGW." The classification of the July 15, 1996 image was used to build AOIs for the 5 classes in the scheme. A separate unsupervised classification for each AOI was run on the delta BGW image, with 75 subclasses specified for each. Scatter diagrams of mean values per signature for the difference bands were plotted as an aid for labeling signatures in conjunction with visual interpretation in order to segregate those signatures that represented change areas from those that have not changed. Cross-tabulation with plot locations could be employed at this stage as validation of labels for change classes. A final map of change categories was built following signature refinement and recoding.

Results and Discussion

Looking at comparative accuracies of attempts to map land cover/use with varying combinations of inventory plots and image analysis techniques for the 1986 image (Figure 8) and for the 1996 image (Figure 9) leads to some interesting observations.

With regard to classification techniques, accuracies for the 1986 image do not show any marked trend from the simpler to the more complex methods, the full-analysis effort yielding only a small general improvement over the initial Isodata attempt. With the 1996 image, by contrast, applying the full suite of image processing techniques gave a decided improvement in accuracy by all measures. One explanation may be that the roads layer used in modeling dated from the late 1990's and introduced some error when used to classify the 1986 image; using a Census roads layer from 1990 might have been a valuable addition in processing the 1986 image. Assessed visually, the output maps from full analysis exhibit larger polygons/patches, and are more similar to other GIS layers in common use and to traditional cover type maps, than are products from simpler methods.

Overall accuracies less than 70% for a classification scheme containing only 5 classes do not represent a particularly impressive outcome, and would be unlikely to meet some needs such as FIA Phase I separation of forest and nonforest for statistical estimation purposes. However, spatial products are often better than their accuracy data. The accuracy criterion applied here was rigorous – testing the classifier on the basis of its ability to agree with FIA/NRI field plot land use definitions – and the field plot locations themselves were imprecise. Even when its formally estimated accuracy is modest, a mapped component can be a valuable supplement to estimates from point-based inventories.

Figure 8: Accuracy of Various Training Sets
1986 Image

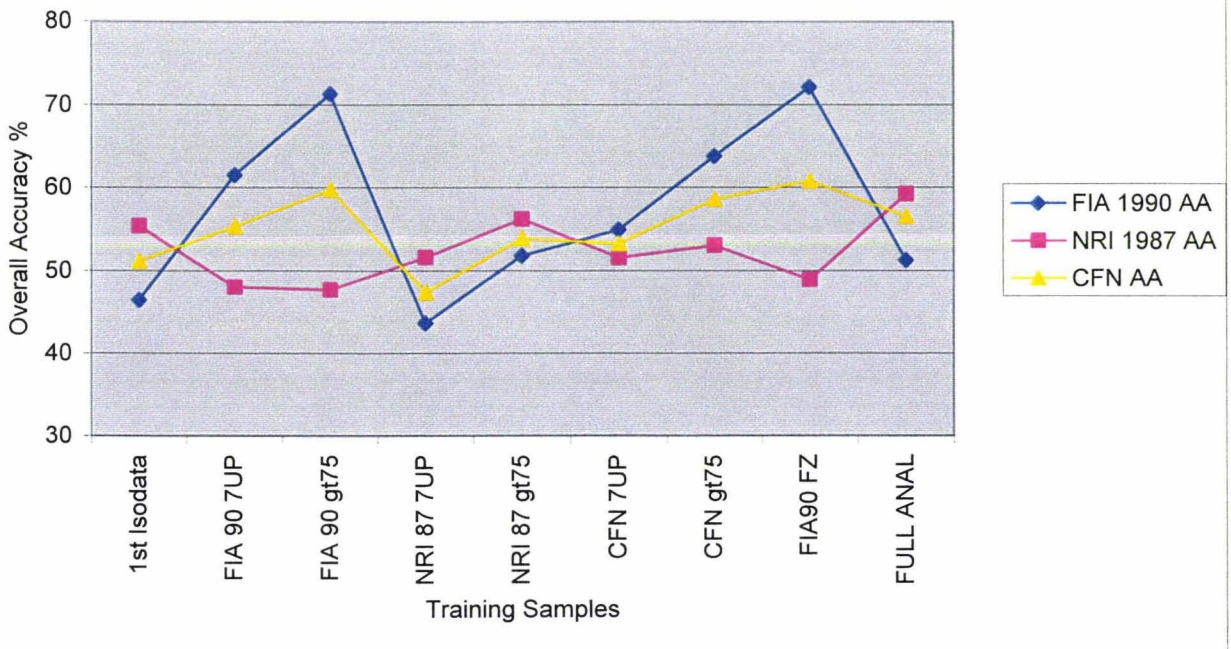
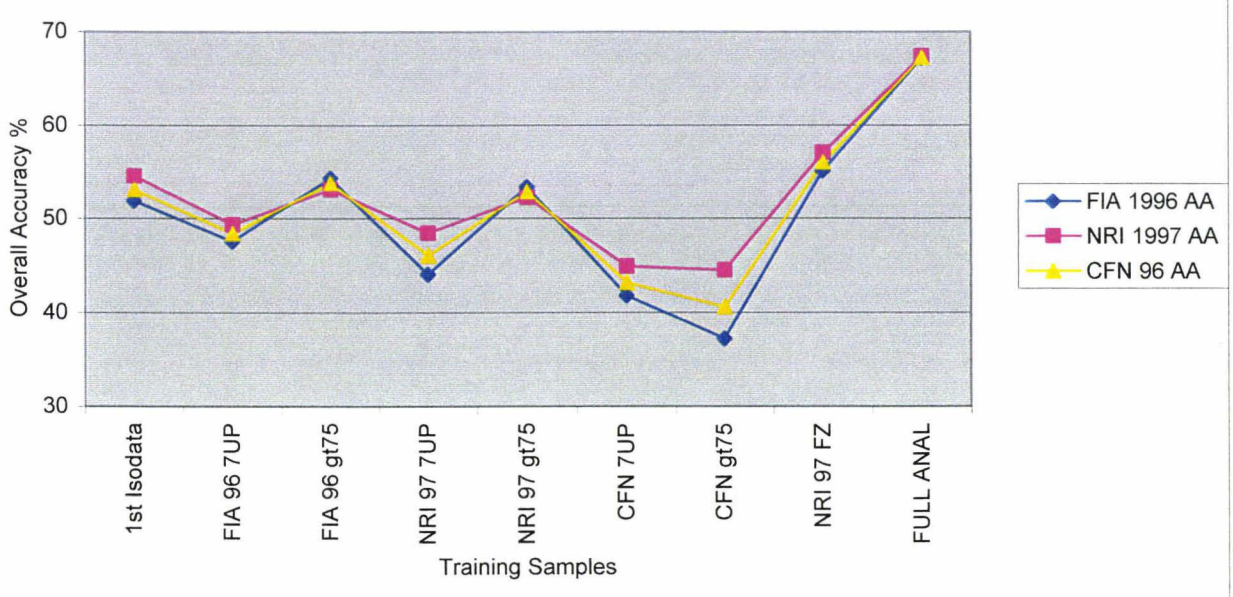


Figure 9: Accuracy of Various Training Sets
1996 Image



Legend for Training Sample Names

1st Isodata – Initial Isodata classification. Training pixels derived from the combined 1987 NRI and 1990 FIA points.

FIA 90 7UP - Training pixels derived from the more homogeneous half of the 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels deleted.

FIA 90 gt75 - Training pixels derived from the more homogeneous half of the 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels & less than 75% agreement with training class deleted.

NRI 87 7UP - Training pixels derived from the more homogeneous half of the 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels deleted.

NRI 87 gt75 - Training pixels derived from the more homogeneous half of the 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels & less than 75% agreement with training class deleted.

CFN 7UP - Training pixels derived from the more homogeneous half of combined 1990 FIA and 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels deleted.

CFN gt75 - Training pixels derived from the more homogeneous half of combined 1990 FIA and 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels & less than 75% agreement with training class deleted.

FIA 90 FZ - Training pixels derived from the more homogeneous half of 1990 FIA points not set aside for accuracy assessment. Fuzzy classification identifying best 2 classes and fuzzy convolution applied.

FULL ANAL - Training pixels derived from the combined 1987 NRI and 1990 FIA points. Full suite of image analysis techniques and modeling applied.

The expected sensitivity of accuracy to the choice of test and training datasets emerges clearly in the 1986 scene, but not in the 1996 scene. Figure 8 (1986) shows that 1990 FIA training sets gave better results when judged against FIA 1990 accuracy assessment points, and 1987 NRI training sets gave better results when judged against 1987 NRI accuracy points. This may be evidence that definitional differences between the two inventories and the manner in which they pass through the crosswalk give rise to an "apples and oranges" situation. However, in the 1996 classifications (Figure 9) the accuracy figures do not exhibit this pattern; they track the classification techniques and show little difference with respect to the datasets employed.

One of the key questions driving the project was whether combining FIA and NRI inventory plots as training data would offer an improvement in classification over either inventory used alone. These results provide little support for that hypothesis. It would seem intuitively appropriate to select crop and herbaceous plots from NRI and forested plots from FIA for training, in order to take advantage the particular strengths of each inventory. This was not attempted in this study, but would be an obvious next step in further analyses.

Both figures seem to show that training sets restricted to signatures yielding 75% agreement with training classes give better results than those in which the only refinement was deletion of 7-pixel, non-invertible signatures. (Though the combined FIA/NRI set in the 1996 image classification is an exception). Editing signatures for agreement is an attempt to eliminate those deriving from heterogeneous plots, from plots unrepresentative of their class, and from plots labeled more according to "use" than "cover" and dissimilar to the larger population of pixels in the broader class of interest.

Area Estimates from Inventories and Maps

FIA and NRI inventories were designed to estimate acreages of various land covers/uses. The maps created by image analysis also provide a total area for each class, and can be compared to areas derived from plot data. Plot-derived acreage estimates for the study area are presented in Table 2, and shown graphically in Figure 10. These data were calculated using county- or state-based expansion factors, and may contain discrepancies in total area on the order of 0.5 percent.

It can be seen that estimates for Forest, Other, Urban, and Water are reasonably close (Water was not separated for 1996 FIA in this table, and is included in Other). Crop and Herbaceous as well as Other and Water were combined in order to compare them as a group, and are also in general agreement. The obvious difference is that FIA tends to identify far more Crop and less Herbaceous than NRI. I suspect NRI takes more care in segregating these classes, and presents a more reliable estimate.

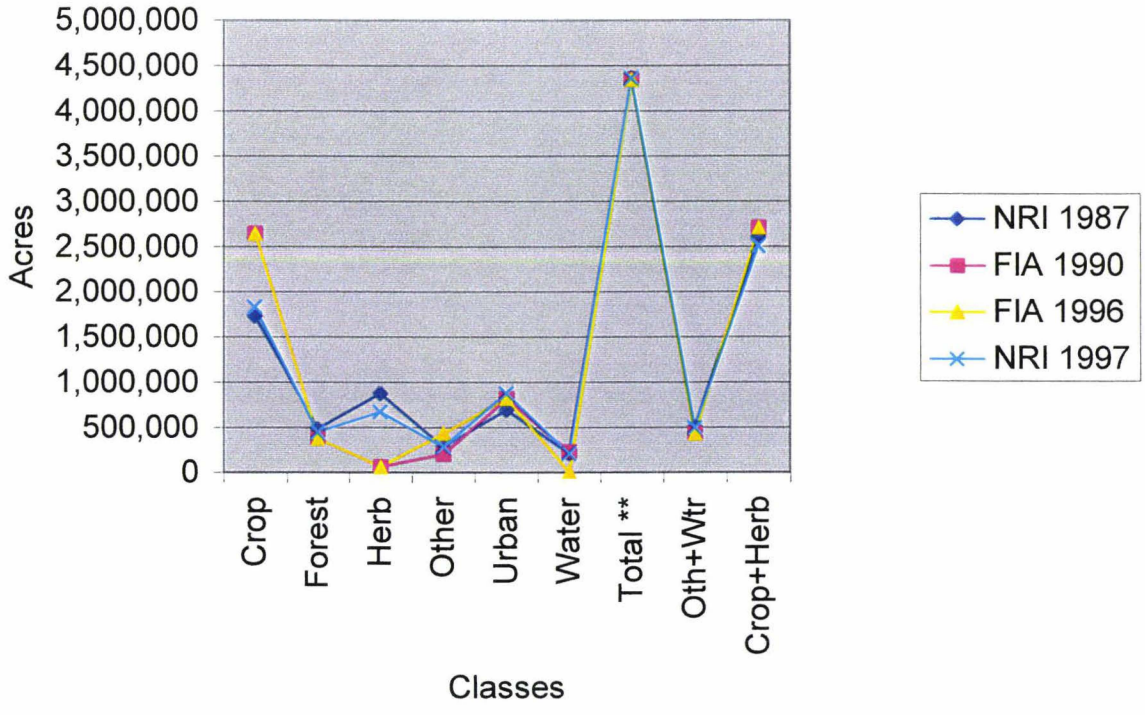
Table 2. Estimated acreages from field inventories

Land Cover	NRI 1987	FIA 1990	FIA 1996	NRI 1997
Crop	1,732,300	2,641,900	2,641,900	1,833,600
Forest	486,600	378,900	377,600	450,800
Herb	878,900	66,200	66,200	676,400
Other	292,200	204,600	440,100	286,100
Urban	700,500	822,700	823,600	878,300
Water	214,500	235,100	0	214,400
Total	**4,367,800**	**4,349,400**	**4,349,400**	**4,367,800**
Other + Water	506,700	439,700	440,100	500,500
Crop + Herbaceous	2,611,200	2,708,100	2,708,100	2,510,000

Figures 11-14 show the class acreages mapped in the various iterations of satellite image classification, graphed against inventory-derived acreages from FIA and NRI. The FIA comparisons (Figures 11-12) show that the initial Isodata and full analyses map more of the Herbaceous class than any of the other efforts, or the inventory estimate itself. This is not a surprising outcome if FIA is in fact underestimating this class: initial unsupervised Isodata signatures for the class would be finding many more spectrally similar pixels in the population, and analyst intervention in full analysis would force a higher representation. Signature refinement, on the other hand, appears to reduce Herbaceous acres, possibly because signatures were dropped when classification results showed a low proportion of training pixels within the class, many true Herbaceous sites having been erroneously called Crop in FIA field inventory.

The Forest class shows a different pattern. Full-analysis acreages are in close agreement with FIA plot-based estimates. With the 1996 image, signature refinements cause the mapped estimate to move closer to the inventory estimate, whereas with the 1986 image the most refined efforts (gt75 and fuzzy classification) are somewhat low. In the 1986 image classifications the refined sets underestimate Other and Urban, and overestimate Crop and Herbaceous combined; this pattern is reversed in the 1996 image analysis. Results for both dates indicate that initial Isodata and full analysis generate mapped acreages closest to the FIA estimate. Did the signature refinement process delete too many good signatures? Possibly so; and the differing full-analysis accuracy outcomes of the 1986 and 1996 images (Figures 8 and 9) may be further evidence of such an effect, as the weaker 1986 full-analysis signature set had been subjected to the refinement process, while the more successful 1996 signatures had not.

Figure 10: Estimated Acreages from Field Inventories



Acreage estimates for the NRI training sets (Figures 13-14) also indicate the value of full image analyses. The 1986 image classification shows general agreement in most classes. Initial Isodata and full analysis overestimated Herbaceous cover to some degree, but were very close when Crop and Herbaceous were considered as a group. Normal agricultural rotation from row crops to forage may easily occur in the interval between the time a field inventory is taken and the time an image is acquired; this may account for a substantial fraction of the confusion between the classes. Forest acreage estimates were much closer together for the 1986 image than for the 1996 image; in both cases, however, the full-analysis estimate was very similar to the inventory estimate. The Urban class also shows some spread between classification techniques, full analysis coming quite close to the inventory estimate in both years of imagery.

--Jim Rack

Figure 11: FIA Acres Estimated and Mapped - 1986 Image

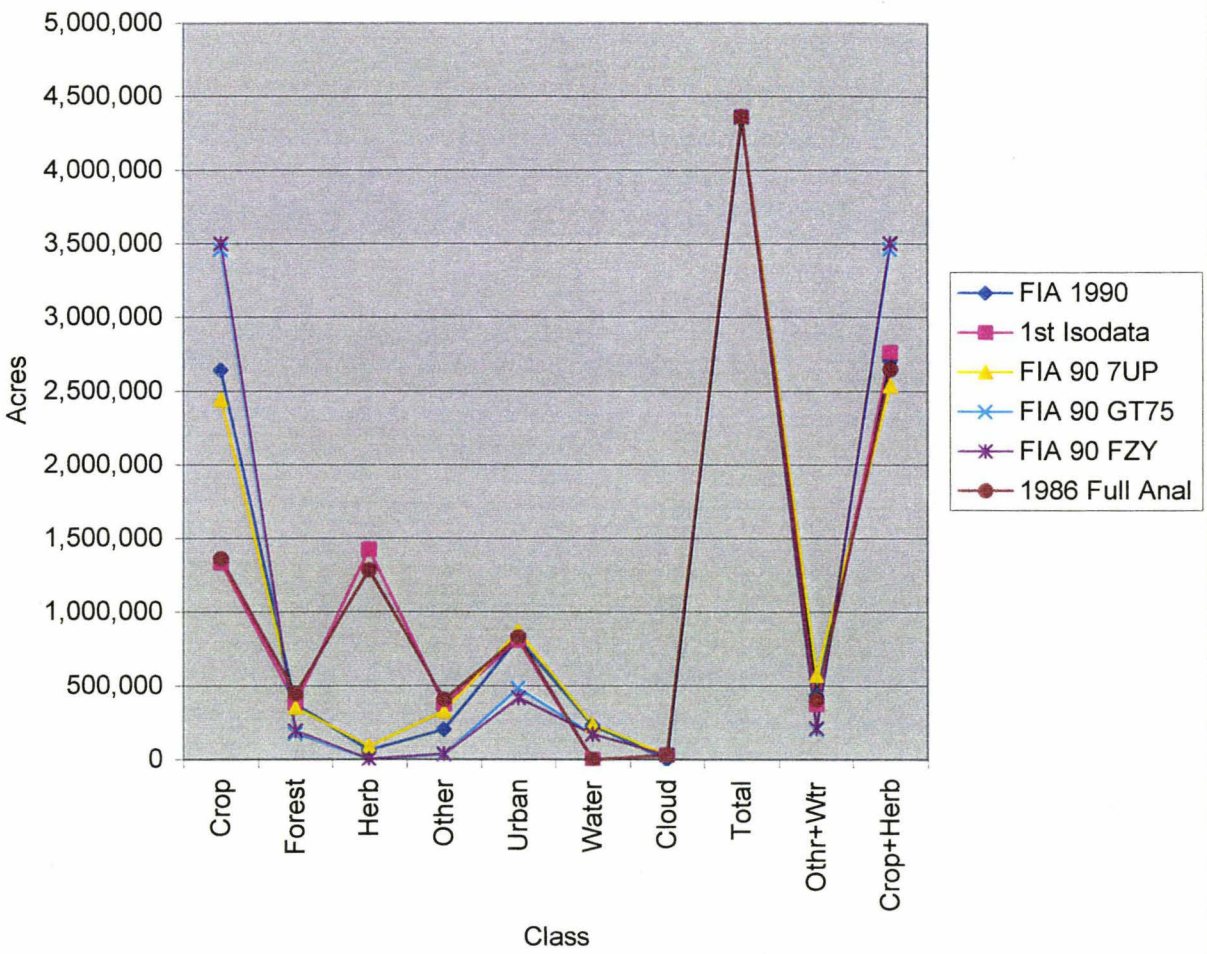


Figure 12: FIA Acres Estimated and Mapped - 1996 Image

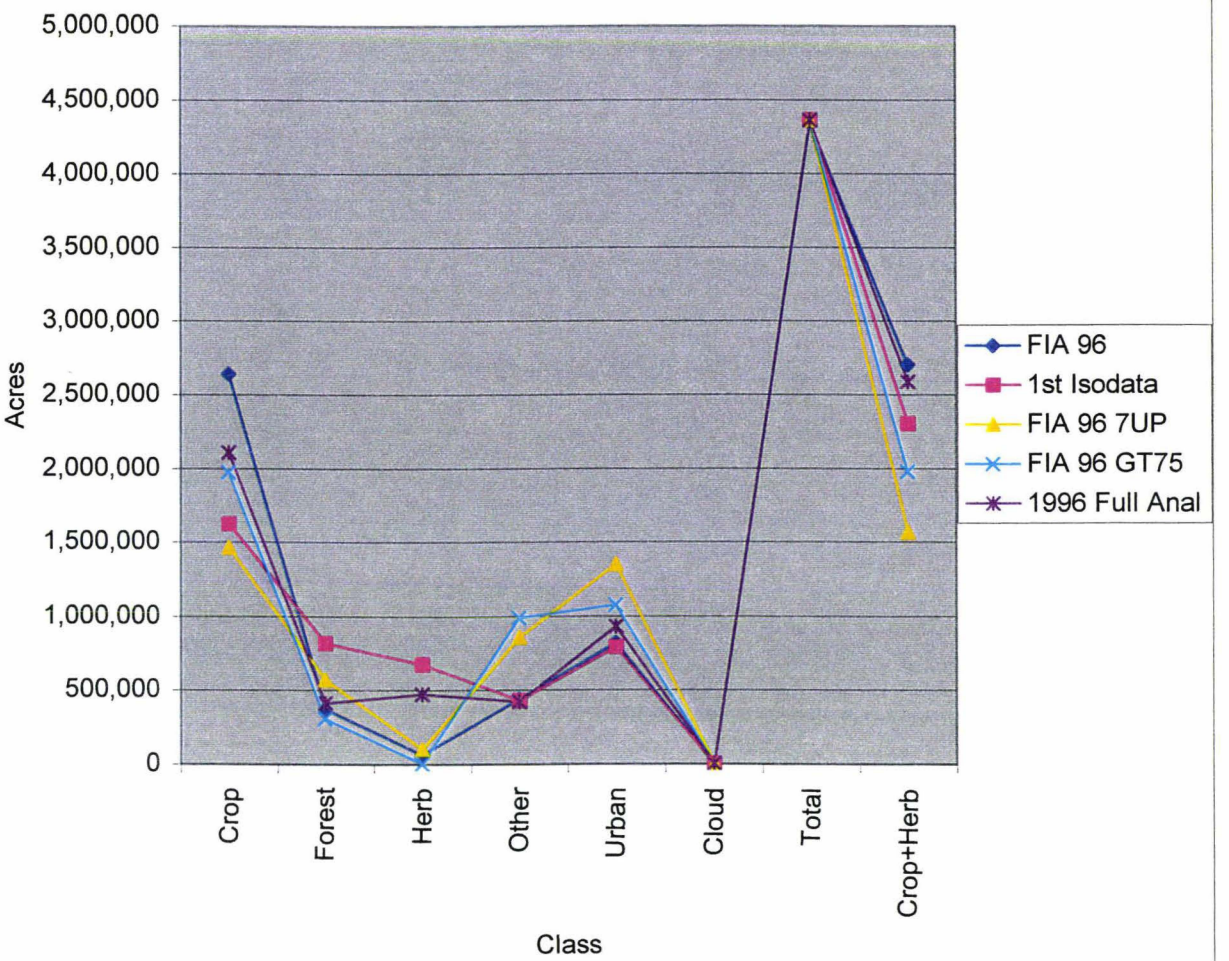


Figure 13: NRI Acres Estimated and Mapped - 1986 Image

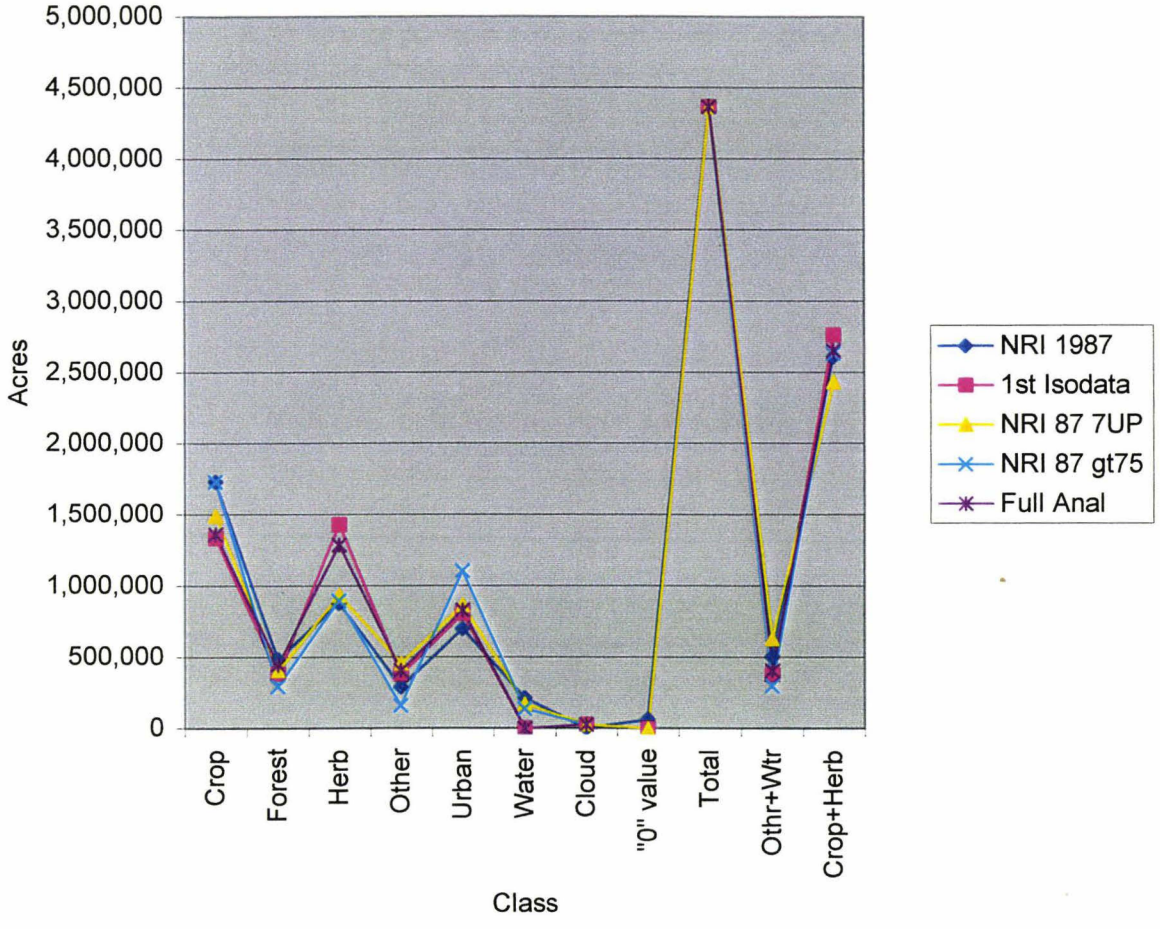
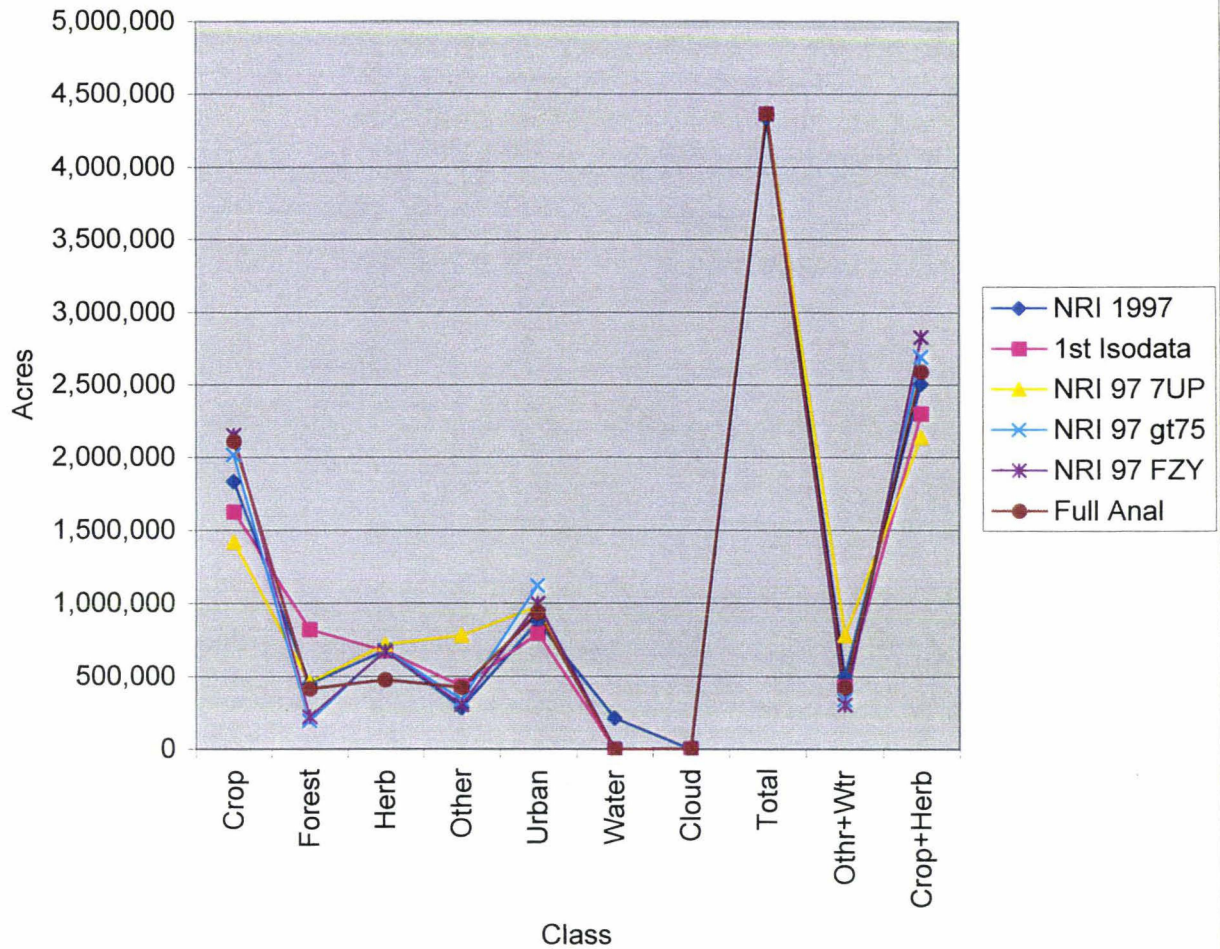


Figure 14: NRI Acres Estimated and Mapped - 1996 Image



Appendices

Appendix A: Draft NRI / FIA Crosswalk (1/24/01)

A crosswalk has been developed to classify land use/cover codes from the two inventories into a simplified classification of five NRI/FIA categories: 1) forest; 2) crop; 3) herbaceous; 4) urban; and 5) other.

Tables 1 and 2 provide the crosswalk for the NRI and FIA data, respectively. The following categories need further discussion to resolve inconsistencies in the NRI/FIA classification:

1. Orchards - NRI codes 001 and 002 for fruit and nut orchards are classified as forest in the NRI/FIA classifications. Signatures would pick these up as forest. However, FIA includes orchards in 51 Cropland with trees. This category includes cropland with scattered single or small groups of trees. Therefore, it is put in the NRI/FIA crop classification.

2. Christmas tree plantations – Signatures are likely to assign these pixels in imagery to forest. FIA separates these plots into a Christmas tree plantation category (46). NRI includes Christmas trees in a category called other land in farms (401) that includes agroforestry and tree plantations, airplane landing strips, greenhouses, mink farms, etc.

3. Rights of way - FIA has one classification for Rights of Way (68) that includes railroads, power lines, pipelines, and maintained roads; this was assigned the NRI/FIA urban classification. The NRI gravel roads (840), dirt roads (850), railroads (860), and private roads (870) were placed in the NRI/FIA other category because of signature concerns.

Table 1. Crosswalk of NRI land cover/use classifications to NRI/FIA classification

NRI Code	NRI Class	NRI/FIA Category
001	Fruit – Orchards	Forest
002	Nuts – Tree	Forest
003	Vineyard	Crop
004	Bush fruit -- woody perennial shrub or bush types	Crop
005	Berries	Crop (MN only)
006	Other	Crop
011	Corn	Crop
012	Sorghum	Crop
013	Soybeans	Crop
014	Cotton	Crop
015	Peanuts	Crop
016	Tobacco	Crop
017	Sugar beets	Crop
018	Potatoes	Crop
019	Other vegetable and truck crops, including melons	Crop
020	All other row crops	Crop
021	Sunflowers	Crop
111	Wheat	Crop
112	Oats	Crop
113	Rice	Other (MN only)
114	Barley	Crop
116	All other close-grown crops	Crop
141	Grass	Herbaceous
142	Legume	Herbaceous
143	Legume-grass	Herbaceous
170	Summer fallow	Herbaceous
171	Aquaculture in a crop rotation	Other
180	Other cropland not planted	Herbaceous
211	Grass	Herbaceous
212	Legume	Herbaceous
213	Grass-forbes-legumes mixed	Herbaceous
250	Rangeland	Herbaceous
341	Forest land,grazed	Forest
342	Forest land,not grazed	Forest
400	Farmsteads and ranch headquarters	Urban
401	Other land in farms (not associated with farmsteads)	Other
410	Conservation Reserve Program (CRP) land	If major contracted practice = grasses and legumes, native planting, wildlife and components, then Herbaceous If trees, then Forest If shallow water, then Other
611	Salt flats	Other
612	Bare exposed rock	Other

NRI Code	NRI Class	NRI/FIA Category
613	Strip mines,quarries, gravel pits,borrow pits	Other
614	Beaches	Other
615	Sand dunes	Other
616	Mixed barren lands	Other
617	Mud flats	Other
618	River wash	Other
619	Oil wasteland	Other
620	Other barren land	Other
630	Permanent snow and ice fields	Other
640	Marshland	Other
650	All other land (requires explanatory note)	Other
700	Urban and built-up, in unit 10 acres or larger	Urban
730	Small built-up, in unit 0.25 to 10 acres	Urban
810	Interstate highway	Urban
820	Paved primary federal and state highways	Urban
830	Other paved roads	Urban
840	Gravel road	Other
850	Dirt road	Other
860	Railroad	Other
870	Other (private)roads	Other
901	Water body, 2 to 40 acres	Other
902	Water body, less than 2 acres	Other
911	Perennial stream less than 66 feet wide	Other
912	Perennial stream 66 to 660 feet wide	Other
913	Perennial stream at least 1/8 mile wide	Other
921	Lake	Other
922	Reservoir	Other
923	Gulf or bay	Other
924	Estuary	Other

Table 2. Crosswalk of FIA land cover/use classifications to NRI/FIA classifications

FIA Code	FIA Class	NRI / FIA Category
20	Timberland	Forest
21	Pastured timberland	Forest
22	Plantations	Forest
40	Unproductive forest land	Forest
41	Reserved forest land-unproductive	Forest
45	Reserved forest land-productive	Forest
46	Christmas tree plantations	Other
50	Reserved, nonforest with trees	Herbaceous
51	Cropland with trees (includes orchards)	Crop
52	Pasture and rangeland with trees	Herbaceous
53	Wooded strip (less than 120 ft wide)	Other
54	Idle farmland with trees	Herbaceous
55	Marsh with trees	Other
56	Narrow windbreaks (<120 ft wide, protects buildings)	Other
57	Wide windbreaks (> 120 ft wide, protects buildings)	Forest
58	Shelterbelt (less than 120 ft wide)	Other
59	Wooded pasture	Forest
61	Cropland without trees	Crop
62	Pasture and rangeland without trees	Herbaceous
64	Idle farmland without trees	Herbaceous
65	Marsh without trees	Other
66	Other farmland (farmsteads and farm buildings)	Urban
67	Urban and other areas without trees	Urban
68	Rights-of-way	Urban
68	Urban and other areas with trees	Urban
69	Nonforest without trees (reserved)	Other
71	Urban forest land (includes wooded areas such as creek bottoms surrounded by houses, military bases, proving grounds)	Forest
80	Noncensus water	Other
89	Noncensus water (reserved)	Other
90	Census water	Other
79	In another country	
96	Inaccessible plot	
97	Dropped plot	
98	Lost (not relocated) plot	
99	Denied access plot	

Appendix B. Error Matrices from Satellite Image Classifications

1. Classified image: i86_isofirst.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the total combined FIA and NRI points in the study area.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Crop	Forest	Data Herb	1781 Other	Total Urban	Water	Row Total	User's Acc
	Crop	500	12	3	8	37	1	561	89.13%
	Forest	21	83	6	8	28	4	150	55.33%
Classified	Herbaceous	432	26	16	33	101	4	612	2.61%
Data	Other	57	1	2	18	17	59	154	50.00%
	Urban	110	9	2	10	151	9	291	51.89%
	Cloud	7	3	0	0	3	0	13	Agree Total
	Ref Total	1127	134	29	77	337	77	1781	827
	Producer's Acc	44.37%	61.94%	55.17%	23.38%	44.81%	76.62%		
							Overall	Accuracy =	46.43%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Crop	Forest	Data Herb	1708 Other	Total Urban	Water	Row Total	User's Acc
	Crop	273	12	80	19	36	0	420	65.00%
	Forest	9	110	9	15	29	0	172	63.95%
Classified	Herbaceous	152	44	184	47	117	0	544	33.82%
Data	Other	23	7	19	18	15	32	114	43.86%
	Urban	44	7	44	17	329	6	447	73.60%
	Cloud	5	1	1	0	4	0	11	Agree Total
	Ref Total	506	181	337	116	530	38	1708	946
	Producer's Acc	53.95%	60.77%	54.60%	15.52%	62.08%	84.21%		
							Overall	Accuracy =	55.39%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Crop	Forest	Data Herb	3464 Other	Total Urban	Water	Row Total	User's Acc
	Crop	773	24	83	27	72	1	980	78.88%
	Forest	30	193	15	23	57	4	322	59.94%
Classified	Herbaceous	584	70	200	80	218	4	1156	17.30%
Data	Other	80	8	21	36	32	91	268	47.39%
	Urban	154	16	46	27	480	15	738	65.04%
	Cloud	0	0	0	0	0	0	0	Agree Total
	Ref Total	1621	311	365	193	859	115	3464	1773
	Producer's Acc	47.69%	62.06%	54.79%	18.65%	55.88%	79.13%		
							Overall	Accuracy =	51.18%

2. Classified image: fia90_7up_wcld.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data		1781	Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	820	31	14	34	118	8	1025	80.00%
	Forest	61	50	7	10	34	1	163	30.67%
Classified	Herbaceous	21	2	1	2	3	0	29	3.45%
Data	Other	75	22	3	11	18	1	130	9.23%
	Urban	138	24	3	12	156	9	342	45.61%
	Cloud	7	3	0	0	3	0	13	
	Water	5	2	1	8	5	58	79	73.42%
	Ref Total	1127	134	29	77	337	77	1781	Agree Total
	Producer's Acc	72.76%	37.31%	3.45%	14.29%	46.29%	75.32%		1096
							Overall	Accuracy =	61.54%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data		1708	Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	378	31	217	56	145	2	829	45.60%
	Forest	21	70	16	13	23	2	145	48.28%
Classified	Herbaceous	7	5	10	1	6	0	29	34.48%
Data	Other	24	31	36	18	35	0	144	12.50%
	Urban	64	37	51	22	311	0	485	64.12%
	Cloud	5	1	1	0	4	0	11	
	Water	7	6	6	6	6	34	65	52.31%
	Ref Total	506	181	337	116	530	38	1708	Agree Total
	Producer's Acc	74.70%	38.67%	2.97%	15.52%	58.68%	89.47%		821
							Overall	Accuracy =	48.07%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data		3464	Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1198	62	231	90	262	10	1853	64.65%
	Forest	82	120	23	23	57	1	306	39.22%
Classified	Herbaceous	28	7	11	3	9	0	58	18.97%
Data	Other	99	53	39	29	53	1	274	10.95%
	Urban	202	61	54	34	467	11	829	56.33%
	Cloud	0	0	0	0	0	0	0	
	Water	12	8	7	14	11	92	144	63.89%
	Ref Total	1621	311	365	193	859	115	3464	Agree Total
	Producer's Acc	73.90%	38.59%	3.01%	15.03%	54.37%	80.00%		1917
							Overall	Accuracy =	55.34%

3. Classified image: fia90_gt75_7cl.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference	Data	1768	Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1051	78	27	63	203	12	1434	73.29%
	Forest	7	48	0	2	16	2	75	64.00%
Classified	Herbaceous	1	0	0	0	0	0	1	0.00%
Data	Other	7	0	1	1	1	0	10	10.00%
	Urban	53	5	1	9	112	14	194	57.73%
	Water	1	0	0	2	2	49	54	90.74%
	Ref Total	1120	131	29	77	334	77	1768	Agree Total
	Producer's Acc	93.84%	36.64%	0.00%	1.30%	33.53%	63.64%		1261
							Overall	Accuracy =	71.32%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference	Data	1697	Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	475	116	315	98	265	1	1270	37.40%
	Forest	3	55	5	4	7	0	74	74.32%
Classified	Herbaceous	0	0	0	0	0	0	0	#DIV/0!
Data	Other	1	2	2	1	4	0	10	10.00%
	Urban	20	6	13	12	248	6	305	81.31%
	Water	2	1	1	1	2	31	38	81.58%
	Ref Total	501	180	336	116	526	38	1697	Agree Total
	Producer's Acc	94.81%	30.56%	0.00%	0.86%	47.15%	81.58%		810
							Overall	Accuracy =	47.73%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference	Data		3464 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1526	194	342	161	467	13	2703	56.46%
	Forest	10	103	5	6	23	2	149	69.13%
Classified	Herbaceous	1	0	0	0	0	0	1	0.00%
Data	Other	8	2	3	2	5	0	20	10.00%
	Urban	73	11	14	21	360	20	499	72.14%
	Water	3	1	1	3	4	80	92	86.96%
	Ref Total	1621	311	365	193	859	115	3464	Agree Total
	Producer's Acc	94.14%	33.12%	0.00%	1.04%	41.91%	69.57%		2071
							Overall	Accuracy =	59.79%

4. Classified image: nri87_7up7d.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels were deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data			1784 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	496	15	8	16	79	2	616	80.52%
	Forest	52	61	3	16	31	4	167	36.53%
Classified	Herbaceous	325	15	9	16	51	2	418	2.15%
Data	Other	124	21	6	19	29	6	205	12.20%
	Urban	127	20	3	9	144	14	317	45.43%
	Water	5	2	0	1	3	50	61	81.97%
	Ref Total	1129	134	29	77	337	78	1784 Agree Total	
	Producer's Acc	43.93%	45.52%	31.03%	24.68%	42.73%	64.10%		779
							Overall	Accuracy =	43.67%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data			1712 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	287	15	99	27	83	1	512	56.05%
	Forest	18	93	23	14	27	0	175	53.14%
Classified	Herbaceous	103	18	131	27	63	0	342	38.30%
Data	Other	35	31	47	32	44	4	193	18.65%
	Urban	59	21	39	13	311	3	446	69.73%
	Water	6	3	0	3	2	30	44	68.18%
	Ref Total	508	181	339	116	530	38	1712 Agree Total	
	Producer's Acc	56.50%	51.38%	38.64%	27.59%	58.68%	78.95%		884
							Overall	Accuracy =	51.64%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data			3464 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	770	29	107	43	162	3	1114	69.12%
	Forest	70	153	25	30	57	4	339	45.13%
Classified	Herbaceous	426	31	139	43	112	2	753	18.46%
Data	Other	159	52	53	51	72	10	397	15.37%
	Urban	185	41	41	22	451	17	757	59.58%
	Water	11	5	0	4	5	79	104	75.96%
	Ref Total	1621	311	365	193	859	115	3464 Agree Total	
	Producer's Acc	47.50%	49.20%	38.08%	26.42%	52.50%	68.70%		1643
							Overall	Accuracy =	47.43%

5. Classified image: nri87_gt75_7cl.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1987 NRI points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data						1784 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	610	25	8	19	69	3	734	83.11%
	Forest	16	69	5	7	20	5	122	56.56%
Classified	Herbaceous	306	10	11	9	57	0	393	2.80%
Data	Other	23	5	1	16	14	9	68	36.76%
	Urban	174	25	4	26	175	17	421	41.57%
	Water	0	0	0	0	2	44	46	95.65%
	Ref Total	1129	134	29	77	337	78	1784	Agree Total
	Producer's Acc	54.03%	51.49%	37.93%	20.78%	51.93%	56.41%		925
							Overall	Accuracy =	51.85%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data						1712 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	326	35	115	23	75	0	574	56.79%
	Forest	4	95	7	12	16	0	134	70.90%
Classified	Herbaceous	95	10	144	24	75	0	348	41.38%
Data	Other	11	7	6	22	13	5	64	42.19%
	Urban	72	34	67	35	349	6	563	61.99%
	Water	0	0	0	0	2	27	29	93.10%
	Ref Total	508	181	339	116	530	38	1712	Agree Total
	Producer's Acc	64.17%	52.49%	42.48%	18.97%	65.85%	71.05%		963
							Overall	Accuracy =	56.25%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data						3464 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	925	59	122	42	143	3	1294	71.48%
	Forest	20	163	12	19	36	5	255	63.92%
Classified	Herbaceous	398	19	154	33	132	0	736	20.92%
Data	Other	34	12	7	38	26	14	131	39.69%
	Urban	244	58	70	61	518	23	974	53.18%
	Water	0	0	0	0	4	70	74	94.59%
	Ref Total	1621	311	365	193	859	115	3464	Agree Total
	Producer's Acc	57.06%	52.41%	42.19%	19.69%	60.30%	60.87%		1868
							Overall	Accuracy =	53.93%

6. Classified image: cfn86_7up7d.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the combined 1987 NRI and 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels were deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data						1768 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	671	17	9	22	81	3	803	83.56%
	Forest	62	72	9	12	31	5	191	37.70%
Classified	Herbaceous	169	12	5	10	29	2	227	2.20%
Data	Other	91	16	3	21	32	8	171	16.96%
	Urban	123	14	2	8	157	14	318	49.37%
	Water	4	0	1	4	4	45	58	77.59%
	Ref Total	1120	131	29	77	334	77	1768 Agree Total	
	Producer's Acc	59.91%	54.96%	17.24%	27.27%	47.01%	58.44%		971
							Overall	Accuracy =	54.92%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data						1697 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	330	22	152	31	103	2	640	51.56%
	Forest	18	100	27	15	23	0	183	54.64%
Classified	Herbaceous	56	8	65	21	34	0	184	35.33%
Data	Other	27	27	45	27	35	2	163	17.79%
	Urban	65	23	44	20	329	9	490	67.14%
	Water	5	0	3	2	2	25	37	67.57%
	Ref Total	501	180	336	116	526	38	1697 Agree Total	
	Producer's Acc	65.87%	55.56%	19.35%	23.28%	62.55%	65.79%		876
							Overall	Accuracy =	51.62%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data						3464 Total	
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1001	39	161	53	183	5	1442	69.42%
	Forest	80	172	36	27	54	5	374	45.99%
Classified	Herbaceous	225	20	70	31	63	2	411	17.03%
Data	Other	118	43	48	48	67	10	334	17.37%
	Urban	188	37	46	28	486	23	808	60.15%
	Water	9	0	4	6	6	70	95	73.68%
	Ref Total	1621	311	365	193	859	115	3464 Agree Total	
	Producer's Acc	61.75%	55.31%	19.18%	24.87%	56.58%	60.87%		1847
							Overall	Accuracy =	53.32%

7. Classified image: cfn86_gt75_7cl.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the combined 1987 NRI and 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data				1768 Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	870	57	16	32	131	14	1120	77.68%
	Forest	13	54	3	4	19	4	97	55.67%
Classified	Herbaceous	87	1	5	8	27	0	128	3.91%
Data	Other	62	8	4	22	22	13	131	26.72%
	Urban	88	11	1	10	133	2	245	54.29%
	Water	0	0	0	1	2	44	47	93.62%
	Ref Total	1120	131	29	77	334	77	1768 Agree Total	
	Producer's Acc	77.68%	41.22%	17.24%	28.57%	39.82%	57.14%		1128
							Overall	Accuracy =	63.80%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data				1697 Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	411	68	219	63	142	2	905	45.41%
	Forest	6	79	4	6	22	0	117	67.52%
Classified	Herbaceous	26	4	50	3	31	0	114	43.86%
Data	Other	11	15	34	31	26	7	124	30.65%
	Urban	47	14	29	12	303	2	407	74.45%
	Water	0	0	0	1	2	27	30	90.00%
	Ref Total	501	180	336	116	526	38	1697 Agree Total	
	Producer's Acc	82.04%	43.89%	14.88%	26.72%	57.60%	71.05%		901
							Overall	Accuracy =	53.09%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data				3464 Total			
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1281	125	235	95	272	16	2024	63.29%
	Forest	19	133	7	10	41	4	214	62.15%
Classified	Herbaceous	113	5	55	11	58	0	242	22.73%
Data	Other	73	23	38	53	48	20	255	28.63%
	Urban	135	25	30	22	436	4	652	66.87%
	Water	0	0	0	2	4	71	77	92.21%
	Ref Total	1621	311	365	193	859	115	3464 Agree Total	
	Producer's Acc	79.03%	42.77%	15.07%	27.46%	50.76%	61.74%		2029
							Overall	Accuracy =	58.57%

8. Classified image: fia90_fz2c_7cl.img. Classification of August 21, 1986 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1990 FIA points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted. Fuzzy classification was performed using 2 classes and fuzzy convolution filter in a 3x3 window.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data			1766 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1066	82	27	66	203	16	1460	73.01%
	Forest	9	45	0	4	10	1	69	65.22%
Classified	Herbaceous	2	0	0	0	0	0	2	0.00%
Data	Other	5	0	1	0	6	1	13	7.69%
	Urban	37	4	1	5	112	6	165	67.88%
	Water	1	0	0	2	3	51	57	89.47%
	Ref Total	1120	131	29	77	334	75	1766	Agree Total
	Producer's Acc	95.18%	34.35%	0.00%	0.00%	33.53%	68.00%		1274
							Overall	Accuracy =	72.14%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data			1697 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	479	115	307	106	255	2	1264	37.90%
	Forest	4	62	7	2	10	1	86	72.09%
Classified	Herbaceous	2	0	0	0	0	0	2	0.00%
Data	Other	2	1	2	2	2	0	9	22.22%
	Urban	12	1	19	5	257	4	298	86.24%
	Water	2	1	1	1	2	31	38	81.58%
	Ref Total	501	180	336	116	526	38	1697	Agree Total
	Producer's Acc	95.61%	34.44%	0.00%	1.72%	48.86%	81.58%		831
							Overall	Accuracy =	48.97%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data			3462 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	1545	197	334	172	457	18	2723	56.74%
	Forest	13	107	7	6	20	2	155	69.03%
Classified	Herbaceous	4	0	0	0	0	0	4	0.00%
Data	Other	7	1	3	2	8	1	22	13.64%
	Urban	49	5	20	10	369	10	463	79.70%
	Water	3	1	1	3	5	82	95	86.32%
	Ref Total	1621	311	365	193	859	113	3462	Agree Total
	Producer's Acc	95.31%	34.41%	0.00%	1.04%	42.96%	72.57%		2105
							Overall	Accuracy =	60.80%

9. Classified image: i86_iatrix.img. Classification of August 21, 1986 image. Training pixels derived from the more homogeneous half of the total combined FIA and NRI points in the study area. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted. Model improvements and other image analysis techniques as discussed in the text were applied.

Reference image: fia90_aapts.img - Half of 1990 FIA randomly selected.

		Reference Data			1781 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	530	7	4	5	23	0	569	93.15%
	Forest	27	92	5	10	27	7	168	54.76%
Classified	Herbaceous	420	15	14	28	85	1	563	2.49%
Data	Other	29	12	5	31	18	66	161	60.25%
	Urban	115	5	1	3	181	3	308	58.77%
	Cloud	6	3	0	0	3	0	12	
	Ref Total	1127	134	29	77	337	77	1781 Agree Total	
	Producer's Acc	47.03%	68.66%	48.28%	40.26%	53.71%	85.71%		914
							Overall	Accuracy =	51.32%

Reference image: nri87_aapts.img - Half of 1987 NRI randomly selected.

		Reference Data			1707 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	293	11	72	11	18	1	406	72.17%
	Forest	18	115	16	19	28	1	197	58.38%
Classified	Herbaceous	135	36	198	42	79	0	490	40.41%
Data	Other	12	7	10	29	25	33	116	53.45%
	Urban	43	12	40	15	376	3	489	76.89%
	Cloud	4	0	1	0	4	0	9	
	Ref Total	505	181	337	116	530	38	1707 Agree Total	
	Producer's Acc	58.02%	63.54%	58.75%	25.00%	70.94%	86.84%		1011
							Overall	Accuracy =	59.23%

Reference image: cfn86_aapts.img - Half of combined NRI 1987 and FIA 1990 randomly selected.

		Reference Data			3463 Total				
		Crop	Forest	Herb	Other	Urban	Water	Row Total	User's Acc
	Crop	823	18	76	16	41	1	975	84.41%
	Forest	45	207	21	29	55	8	365	56.71%
Classified	Herbaceous	553	50	212	70	163	1	1049	20.21%
Data	Other	41	19	15	60	43	99	277	57.40%
	Urban	158	17	41	18	557	6	797	69.89%
	Ref Total	1620	311	365	193	859	115	3463 Agree Total	
	Producer's Acc	50.80%	66.56%	58.08%	31.09%	64.84%	86.09%		1958
							Overall	Accuracy =	56.54%

10. Classified image: i96_isofirst.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the total combined FIA and NRI points in the study area.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	588	18	9	25	59	699	84.12%
	Forest	157	92	6	19	61	335	27.46%
Classified	Herbaceous	204	5	9	12	36	266	3.38%
Data	Other	54	8	1	86	32	181	47.51%
	Urban	123	11	4	12	149	299	49.83%
	Ref Total	1126	134	29	154	337	1780 Agree Total	
	Producer's Acc	52.22%	68.66%	31.03%	55.84%	44.21%		924
						Overall	Accuracy =	51.91%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	296	12	73	31	87	499	59.32%
	Forest	76	93	20	28	59	276	33.70%
Classified	Herbaceous	61	6	57	23	65	212	26.89%
Data	Other	18	15	7	22	28	90	24.44%
	Urban	34	8	21	7	347	417	83.21%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	61.03%	69.40%	32.02%	19.82%	59.22%		815
						Overall	Accuracy =	54.55%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	884	30	82	56	146	1198	73.79%
	Forest	233	185	26	47	120	611	30.28%
Classified	Herbaceous	265	11	66	35	101	478	13.81%
Data	Other	72	23	8	108	60	271	39.85%
	Urban	157	19	25	19	495	715	69.23%
	Ref Total	1611	268	207	265	922	3273 Agree Total	
	Producer's Acc	54.87%	69.03%	31.88%	40.75%	53.69%		1738
						Overall	Accuracy =	53.10%

11. Classified image: fia96_7up.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1996 FIA points not set aside for accuracy assessment. Signatures with too few pixels were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	539	22	10	28	63	662	81.42%
	Forest	101	61	6	12	44	224	27.23%
Classified	Herbaceous	29	6	1	2	9	47	2.13%
Data	Other	173	22	4	85	60	344	24.71%
	Urban	284	23	8	27	161	503	32.01%
	Ref Total	1126	134	29	154	337	1780	Agree Total
	Producer's Acc	47.87%	45.52%	3.45%	55.19%	47.77%		847
						Overall	Accuracy =	47.58%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	248	23	64	30	74	439	56.49%
	Forest	59	66	18	17	54	214	30.84%
Classified	Herbaceous	14	3	7	3	15	42	16.67%
Data	Other	60	15	39	35	61	210	16.67%
	Urban	104	27	50	26	382	589	64.86%
	Ref Total	485	134	178	111	586	1494	Agree Total
	Producer's Acc	51.13%	49.25%	3.93%	31.53%	65.19%		738
						Overall	Accuracy =	49.40%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	787	45	74	58	136	1100	71.55%
	Forest	160	127	24	29	98	438	29.00%
Classified	Herbaceous	43	9	8	5	24	89	8.99%
Data	Other	233	37	43	120	121	554	21.66%
	Urban	388	50	58	53	543	1092	49.73%
	Ref Total	1611	268	207	265	922	3273	Agree Total
	Producer's Acc	48.85%	47.39%	3.86%	45.28%	58.89%		1585
						Overall	Accuracy =	48.43%

12. Classified image: fia96_gt75_wcld.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1996 FIA points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1784 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	677	41	16	32	90	856	79.09%
	Forest	37	48	1	12	21	119	40.34%
Classified	Herbaceous	0	1	0	0	0	1	0.00%
Data	Other	206	26	6	88	70	396	22.22%
	Urban	209	18	6	23	156	412	37.86%
	Ref Total	1129	134	29	155	337	1784 Agree Total	
	Producer's Acc	59.96%	35.82%	0.00%	56.77%	46.29%		969
						Overall	Accuracy =	54.32%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	328	42	93	44	99	606	54.13%
	Forest	27	54	5	11	21	118	45.76%
Classified	Herbaceous	0	0	0	0	0	0	#DIV/0!
Data	Other	62	25	55	35	89	266	13.16%
	Urban	68	13	25	21	377	504	74.80%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	67.63%	40.30%	0.00%	31.53%	64.33%		794
						Overall	Accuracy =	53.15%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	1004	83	109	76	188	1460	68.77%
	Forest	63	102	6	23	42	236	43.22%
Classified	Herbaceous	0	1	0	0	0	1	0.00%
Data	Other	268	51	61	122	159	661	18.46%
	Urban	276	31	31	44	533	915	58.25%
	Ref Total	1611	268	207	265	922	3273 Agree Total	
	Producer's Acc	62.32%	38.06%	0.00%	46.04%	57.81%		1761
						Overall	Accuracy =	53.80%

13. Classified image: nri97_7up_wcld.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1997 NRI points not set aside for accuracy assessment. Signatures with too few pixels were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	488	30	9	26	59	612	79.74%
	Forest	79	53	4	13	31	180	29.44%
Classified	Herbaceous	214	14	4	11	48	291	1.37%
Data	Other	167	21	9	82	42	321	25.55%
	Urban	178	16	3	22	157	376	41.76%
	Ref Total	1126	134	29	154	337	1780 Agree Total	
	Producer's Acc	43.34%	39.55%	13.79%	53.25%	46.59%		784
						Overall	Accuracy =	44.04%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	262	24	66	32	78	462	56.71%
	Forest	35	56	11	10	31	143	39.16%
Classified	Herbaceous	71	9	48	17	77	222	21.62%
Data	Other	50	31	26	34	76	217	15.67%
	Urban	67	14	27	18	324	450	72.00%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	54.02%	41.79%	26.97%	30.63%	55.29%		724
						Overall	Accuracy =	48.46%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	750	54	75	58	137	1074	69.83%
	Forest	114	109	15	23	62	323	33.75%
Classified	Herbaceous	285	23	52	28	124	512	10.16%
Data	Other	217	52	35	116	118	538	21.56%
	Urban	245	30	30	40	481	826	58.23%
	Ref Total	1611	268	207	265	922	3273 Agree Total	
	Producer's Acc	46.55%	40.67%	25.12%	43.77%	52.17%		1508
						Overall	Accuracy =	46.07%

14. Classified image: nri97_gt75_wcld.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1997 NRI points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	683	54	16	43	91	887	77.00%
	Forest	12	43	1	8	15	79	54.43%
Classified	Herbaceous	172	12	1	14	49	248	0.40%
Data	Other	69	5	4	52	11	141	36.88%
	Urban	190	20	7	37	171	425	40.24%
	Ref Total	1126	134	29	154	337	1780 Agree Total	
	Producer's Acc	60.66%	32.09%	3.45%	33.77%	50.74%		950
						Overall	Accuracy =	53.37%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	332	59	86	47	125	649	51.16%
	Forest	7	35	1	6	16	65	53.85%
Classified	Herbaceous	78	22	47	20	73	240	19.58%
Data	Other	10	3	15	11	16	55	20.00%
	Urban	58	15	29	27	356	485	73.40%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	68.45%	26.12%	26.40%	9.91%	60.75%		781
						Overall	Accuracy =	52.28%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	1015	113	102	90	216	1536	66.08%
	Forest	19	78	2	14	31	144	54.17%
Classified	Herbaceous	250	34	48	34	121	487	9.86%
Data	Other	79	8	19	63	27	196	32.14%
	Urban	248	35	36	64	527	910	57.91%
	Ref Total	1611	268	207	265	922	3273 Agree Total	
	Producer's Acc	63.00%	29.10%	23.19%	23.77%	57.16%		1731
						Overall	Accuracy =	52.89%

15. Classified image: cfn96_7up_wcld.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the combined 1997 NRI and 1996 FIA points not set aside for accuracy assessment. Signatures with too few pixels were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	430	17	9	23	49	528	81.44%
	Forest	139	82	3	32	53	309	26.54%
Classified	Herbaceous	170	7	4	4	42	227	1.76%
Data	Other	203	22	9	80	45	359	22.28%
	Urban	184	6	4	15	148	357	41.46%
	Ref Total	1126	134	29	154	337	1780 Agree Total	
	Producer's Acc	38.19%	61.19%	13.79%	51.95%	43.92%		744
						Overall	Accuracy =	41.80%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	214	17	49	19	50	349	61.32%
	Forest	81	81	25	28	83	298	27.18%
Classified	Herbaceous	67	4	42	12	69	194	21.65%
Data	Other	66	22	35	34	84	241	14.11%
	Urban	57	10	27	18	300	412	72.82%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	44.12%	60.45%	23.60%	30.63%	51.19%		671
						Overall	Accuracy =	44.91%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3280 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	645	34	58	42	99	878	73.46%
	Forest	221	163	28	60	136	608	26.81%
Classified	Herbaceous	239	11	46	16	110	422	10.90%
Data	Other	270	44	44	115	130	603	19.07%
	Urban	241	16	31	33	448	769	58.26%
	Ref Total	1616	268	207	266	923	3280 Agree Total	
	Producer's Acc	39.91%	60.82%	22.22%	43.23%	48.54%		1417
						Overall	Accuracy =	43.20%

16. Classified image: cfn96_gt75_wcld.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the combined 1997 NRI and 1996 FIA points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	350	13	8	8	23	402	87.06%
	Forest	138	75	3	20	54	290	25.86%
Classified	Herbaceous	303	17	5	22	57	404	1.24%
Data	Other	180	15	7	75	46	323	23.22%
	Urban	155	14	6	29	157	361	43.49%
	Ref Total	1126	134	29	154	337	1780 Agree Total	
	Producer's Acc	31.08%	55.97%	17.24%	48.70%	46.59%		662
						Overall	Accuracy =	37.19%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	184	8	35	18	31	276	66.67%
	Forest	71	79	10	22	81	263	30.04%
Classified	Herbaceous	127	20	65	25	102	339	19.17%
Data	Other	67	14	39	28	63	211	13.27%
	Urban	36	13	29	18	309	405	76.30%
	Ref Total	485	134	178	111	586	1494 Agree Total	
	Producer's Acc	37.94%	58.96%	36.52%	25.23%	52.73%		665
						Overall	Accuracy =	44.51%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3280 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	537	21	43	26	54	681	78.85%
	Forest	209	154	13	42	136	554	27.80%
Classified	Herbaceous	432	37	70	47	158	744	9.41%
Data	Other	247	29	46	104	109	535	19.44%
	Urban	191	27	35	47	466	766	60.84%
	Ref Total	1616	268	207	266	923	3280 Agree Total	
	Producer's Acc	33.23%	57.46%	33.82%	39.10%	50.49%		1331
						Overall	Accuracy =	40.58%

17. Classified image: nri97_fz2c5cl.img. Classification of July 15, 1996 image using unsupervised (Isodata) techniques. Training pixels derived from the more homogeneous half of the 1997 NRI points not set aside for accuracy assessment. Signatures with too few pixels and with less than 75% agreement (generally) with training class were deleted. Fuzzy classification was performed using 2 classes and fuzzy convolution filter in a 3x3 window.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1780 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	716	63	16	37	88	920	77.83%
	Forest	13	43	0	6	19	81	53.09%
Classified	Herbaceous	178	13	4	27	48	270	1.48%
Data	Other	66	2	4	52	16	140	37.14%
	Urban	153	13	5	32	166	369	44.99%
	Ref Total	1126	134	29	154	337	1780	Agree Total
	Producer's Acc	63.59%	32.09%	13.79%	33.77%	49.26%		981
						Overall	Accuracy =	55.11%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1494 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	365	49	79	43	111	647	56.41%
	Forest	10	46	3	4	19	82	56.10%
Classified	Herbaceous	69	27	57	23	76	252	22.62%
Data	Other	9	3	15	18	13	58	31.03%
	Urban	32	9	24	23	367	455	80.66%
	Ref Total	485	134	178	111	586	1494	Agree Total
	Producer's Acc	75.26%	34.33%	32.02%	16.22%	62.63%		853
						Overall	Accuracy =	57.10%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3273 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	1081	112	95	80	199	1567	68.99%
	Forest	23	89	3	10	38	163	54.60%
Classified	Herbaceous	247	40	61	50	123	521	11.71%
Data	Other	75	5	19	70	29	198	35.35%
	Urban	185	22	29	55	533	824	64.68%
	Ref Total	1611	268	207	265	922	3273	Agree Total
	Producer's Acc	67.10%	33.21%	29.47%	26.42%	57.81%		1834
						Overall	Accuracy =	56.03%

18. Classified image: i96_iatrix.img. Classification of July 15, 1996 image. Training pixels derived from the more homogeneous half of the total combined FIA and NRI points in the study area. Model improvements and other image analysis techniques as discussed in the text were applied.

Reference image: fia96_aapts.img - Half of 1996 FIA randomly selected.

		Reference Data			1783 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	795	30	15	22	60	922	86.23%
	Forest	33	83	3	14	24	157	52.87%
Classified	Herbaceous	147	3	5	11	16	182	2.75%
Data	Other	32	9	3	100	22	166	60.24%
	Urban	121	9	3	8	215	356	60.39%
	Ref Total	1128	134	29	155	337	1783	Agree Total
	Producer's Acc	70.48%	61.94%	17.24%	64.52%	63.80%		1198
						Overall	Accuracy =	67.19%

Reference image: nri97_aapts.img - Half of 1997 NRI randomly selected.

		Reference Data			1497 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	386	27	76	43	54	586	65.87%
	Forest	15	86	12	16	35	164	52.44%
Classified	Herbaceous	48	3	56	8	25	140	40.00%
Data	Other	8	10	8	30	22	78	38.46%
	Urban	30	8	26	14	451	529	85.26%
	Ref Total	487	134	178	111	587	1497	Agree Total
	Producer's Acc	79.26%	64.18%	31.46%	27.03%	76.83%		1009
						Overall	Accuracy =	67.40%

Reference image: cfn96_aapts.img - Half of combined NRI 1997 and FIA 1996 randomly selected.

		Reference Data			3279 Total			
		Crop	Forest	Herb	Other	Urban	Row Total	User's Acc
	Crop	1181	57	91	65	114	1508	78.32%
	Forest	48	169	15	30	59	321	52.65%
Classified	Herbaceous	195	6	61	19	41	322	18.94%
Data	Other	40	19	11	130	44	244	53.28%
	Urban	151	17	29	22	665	884	75.23%
	Ref Total	1615	268	207	266	923	3279	Agree Total
	Producer's Acc	73.13%	63.06%	29.47%	48.87%	72.05%		2206
						Overall	Accuracy =	67.28%